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Measurement of Ice/Propeller Interaction Parameters — M.V. Robert Lemeur

Summary Report

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MEASUREMENT OF ICE/PROPELLER INTERACTION PARAMETERS - MV ROBERT LEMEUR SUMMARY REPORT

PREPARED FOR THE TRANSPORTATION DEVELOPMENT CENTRE

BY: J. DUFF
K. KIRBY
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CANADIAN MARINE DRILLING LTD.
CALGARY, ALBERTA
AUGUST, 1985

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transport Canada Research and Development Centre.

The contractors assume no responsibility for any subsequent use of the information contained in this report.

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17. Abstract

This report documents the preliminary analysis of the data collected on board the M.V. Robert LeMeur during the 1984 operating season, including five days of dedicated tests in June 1984. Analysis of the propulsion train components is performed. Propeller ice impact forces are analyzed and the response of the shafting system is determined. A model of blade-ice interaction is proposed based on the data analysis. A model of the yoke-pin and shaft response to the ice torque and thrust is also developed. Software used during data analysis is fully documented. Conclusions pertinent to regulatory purposes are derived.

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17. Résumé

Ce rapport rend compte des résultats de l'analyse préliminaire des données recueillies à bord du Robert-LeMeur au cours de la saison d'exploitation 1984, y compris les cinq journées consacrées aux essais spécialisés en juin de cette année. L'analyse a porté sur les organes de la chaîne cinématique et, notamment, sur les chocs subis par les pales d'hélice et leurs répercussions sur la ligne d'arbres. Un modèle de l'interaction glaces/pales est proposé, fondé sur l'analyse des données, ainsi qu'un modèle figurant la tenue de l'arbre et de la goupille d'accouplement au couple de torsion et à la poussée résultant de cette interaction. Les logiciels utilisés sont décrits en détail. Sont enfin présentées des conclusions intéressant la réglementation actuelle et celle à venir.

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FOREWORD

This document is the summary of the final report in a series of reports dealing with the measurement of ice/propeller interaction on the MV Robert LeMeur. The first of these reports was from a previous study "The MV Robert LeMeur Nozzle Propeller Ice Force Measurement Project - 1983 Final Report". For the (Transportation Development Centre (Transport Canada No. TP5685E), executed by Canmar. The 1983 project had only partial success due to significant failures of the propeller blade strain gauges. The current project expands upon the aims of the 1983 project by measuring more signals and developing analytical models of ice/propeller interaction.

The current project's work is detailed in two reports, the first of which is entitled "Measurement of Ice/Propeller Interaction Parameters Engineering and Field Tests", Transportation Development Centre Transport Canada No. TP.6842E, executed by Canmar. The final report, of which this is a summary, is entitled "Measurement of Ice/Propeller Interaction Parameters - MV Robert LeMeur", Transportation Development Centre Transport Canada No. TP. 6839E, TP. 6840E & TP. 6842E.

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1. OVERVIEW

This project dealt with the measurements of ice loads on the propeller blade of the MV Robert LeMeur. Three phases of the project were identified:

- Preparatory, or engineering phase, which took place between December 1983 and June 1984.
- Field testing phase, which took place in June-July 1984.
- Post testing and data analysis phase which took place in July 1984 - March 1985.

The preparatory and testing phases were documented in the report entitled "Measurement of Ice Interaction Parameters - Engineering and Field Tests" issued in October 1984, referred to as Milestone 1.

An interim report, titled Milestone 2, was produced in December 1984 in order to fulfill the terms of the contract. Milestone 2 was superceded by the final report. The final report deals with the post-testing and data analysis phase of the project. This report is a summary of the final report, entitled "Measurement of ice/propeller interaction parameters - M V Robert Lemeur".

2. PROJECT OBJECTIVES

The objectives of the project were:

- To measure directly the magnitude and location of ice interaction forces on the blade of a controllable pitch propeller (CPP) working in a nozzle, and the resultant effects on the CPP hub mechanism and on the propeller shaft.
- To record the position of the tail shaft within the stern tube bearing during heavy ice propeller interaction.
- To make a record of the tests and results which will be adequate for the future reference and re-analysis, if desired.
- To reduce data to engineering units and to analyse it to provide a coherent picture of the ice/propeller interaction phenomena, bearing in mind the ultimate use of the data in the generation of design criteria and regulations.

Milestone 1 report documented the type and choice of instrumentation used on the MV Robert LeMeur; it described in detail the field test program and introduced a series of exploratory analytical models developed to describe the relationships between external loads and responses in selected drive train components.

The final report documents the work performed in the post-data collection phase. The objectives of this phase were:

- To prepare, preserve, and protect the test data for later use.
- To prepare software packages in a "user friendly" format for use by other research workers.
- To de-bug the data.
- To conduct a preliminary analysis of the data.
- To use the analysis to report on the following topics:

  i. Ice/Propeller Interaction: To determine from the test data, the types and magnitudes of ice/propeller encounters, including hydrodynamic effects. To compare the frequency and severity of ice interactions with ship operating variables. To evaluate the Ice Interaction Models proposed in Milestone 1 and offer amended versions.

ii. Propeller blade: To observe the response of the instrumented blade to its interaction with ice, especially with reference to the effect of dynamic magnification. To evaluate the accuracy of the Simple Beam Blade Model proposed in Milestone 1.

iii. Yoke Pin: To combine the findings of the static calibrations, the field test results, and the Yoke Pin Model to determine the friction at the blade foot and its influence in attenuating load impulses from the blade to the yoke pin.

iv. Shaft: To measure the shaft torque and thrust responses during ice/propeller interactions and compare with the simple Shaft Models proposed in Milestone 1. To evaluate the possibility of substituting shaft strain-gauges for the blade strain-gauges for interpreting ice loading conditions on a propulsion system over an extended period of time. To collect shaft torque and thrust fluctuations data over an operating season and determine their statistical importance.

v. Bearing: To observe the motion of the tail shaft within the stern-tube bearing and explain its significance for bearing design.

vi. Long Term Shaft Statistics: To determine how representative the 343 tests were of a complete operating season. To determine shaft torque and thrust cycles during the whole operating season for potential future use in determining propulsion train fatigue. To record sample shaft torque and thrust signals during the largest shaft torque event of the operating season.

3. BACKGROUND INFORMATION

3.1 Ship Data

The basic parameters of the MV Robert LeMeur are listed in Table 3-1. The ship is designated as a CASPPR Class 3 ice breaking supply vessel, and classed by Lloyds Register as 100A1. It was built by Burrard Yarrows Shipyard in Vancouver, British Columbia, in 1982 for Dome Petroleum Ltd. Its duties have been to support the Canmar drilling fleet in the Beaufort Sea.

The ship has two engines, each of approximately 3,530 kW. Each engine powers a controllable pitch propeller (CPP) through a single ratio step down gear box. The propellers are shrouded by custom designed nozzles.

The general arrangement of the MV Robert LeMeur is shown in Figure 3-1.

The locations of the transducers on the starboard shaft are shown in Figure 3-2.

3.2 Ice Block Size Distribution

The ice block size distribution for the field trials during June/July 1984 was determined from the analysis of photographs taken during the field program.

Figure 3-3 shows the excedence probability of ice block size distribution observed during the five day test period.

Ship:

Length Overall	82.8 m
Breadth Moulded	18.0 m
Icebreaking Draft	5.5 m
Deadweight	2690.4 tonnes
Engine Power at M.C.R.	3530 kW

BEAM/Propeller Dia Ratio = 6

Propulsion:		NUMBER
Engine	M.A.K. 12M45EV	2
Clutch	L&S PNEUMAFLEX KA320MD	2
Gearbox	L&S GCE8505	2

Propellers

LIPS	CPP
Hub Type	4C115W
Number of Blades	4
Propeller Speed	209 RPM
Hub to Prop. Dia. Ratio	0.367
Propeller Diameter	3.0 m

Pitch Mechanism

Design pitch angle at 0.7 r/R	26.48°
Maximum astern pitch angle	19.66°
Bollard Pitch angle	26.12°

BLADE:

Mass of Blade w/o Foot	452 kg (C.O.G. - 0.947 m)
Mass of Blade w/ Foot	615 kg (C.O.G. - 0.819 m)
Material	Cunial Bronze
Ultimate	647 MPa
Yield	260 MPa
Elongation	20%
Blade width	1.0 m
Thickness of blade tip	.025 m
Young's Modulus E	1.3×10^{11} Pa
Poisson Ratio	0.3
	48 800 MPa
U.T.S.	647 MPa
Yield	260 MPa

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: BASIC PARAMETERS M.V. ROBERT LEMEUR DATA
		TABLE 3.1

Nozzle:

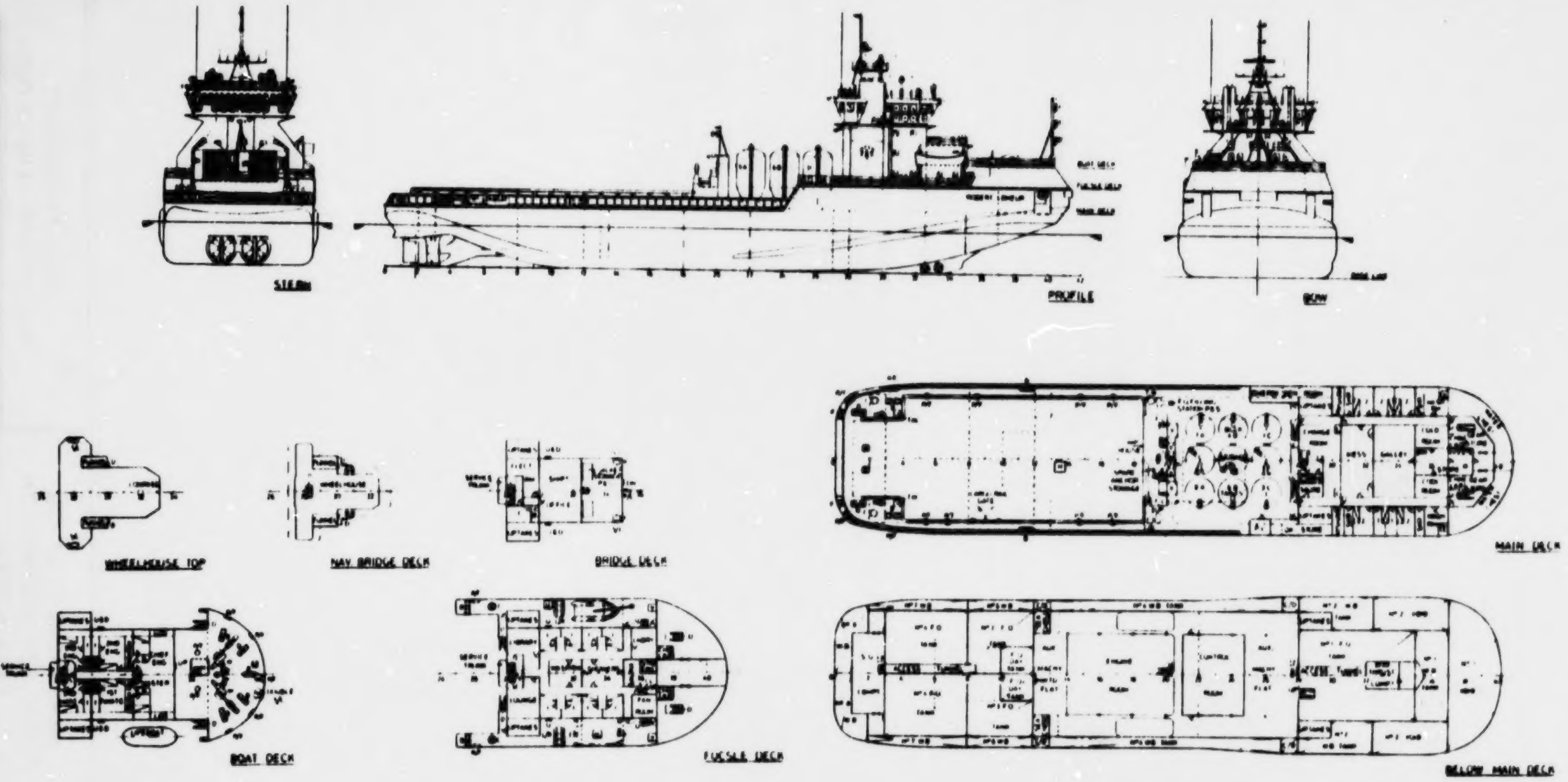
Nozzle Inside Diameter	3.03 m
Nozzle Length	1.4 m
Length to Prop. Dia. Ratio	0.4667

List of natural frequencies of the propulsion train components.

Shaft	3.48 Hz		
Blade	13.9 Hz		
Blade Bending (Fixed-Free Condition)	40 Hz	In Water	Fundamental
	90 Hz	In Air	Fundamental
	120 Hz	In Air	Second Mode
Blade Torsion	138 Hz	In Air	
Shaft Longitudinal (Including propeller, added mass and flywheel)	25.5 Hz		fundamental
	76.1 Hz		second
	106.0 Hz		third
Shaft Torque	3.58 Hz		fundamental
	13.89 Hz		second
	27.12 Hz		third
	42.27 Hz		fourth
Ship Hull Vibrations	2.24 Hz		

Construction Pitch Angle

r/R (-)	CONST (DEG)
0.37	39.5
0.40	37.6
0.5	32.8
0.6	29.3
0.7	26.5
0.8	24.2
0.85	23.3
0.90	22.4
0.95	21.5
1.00	20.8


STERN
PROFILE
BOW
WHEELHOUSE TOP
NAV BRIDGE DECK
BRIDGE DECK
MAIN DECK
BOAT DECK
FOCSLE DECK
BELOW MAIN DECK

GENERAL PARTICULARS

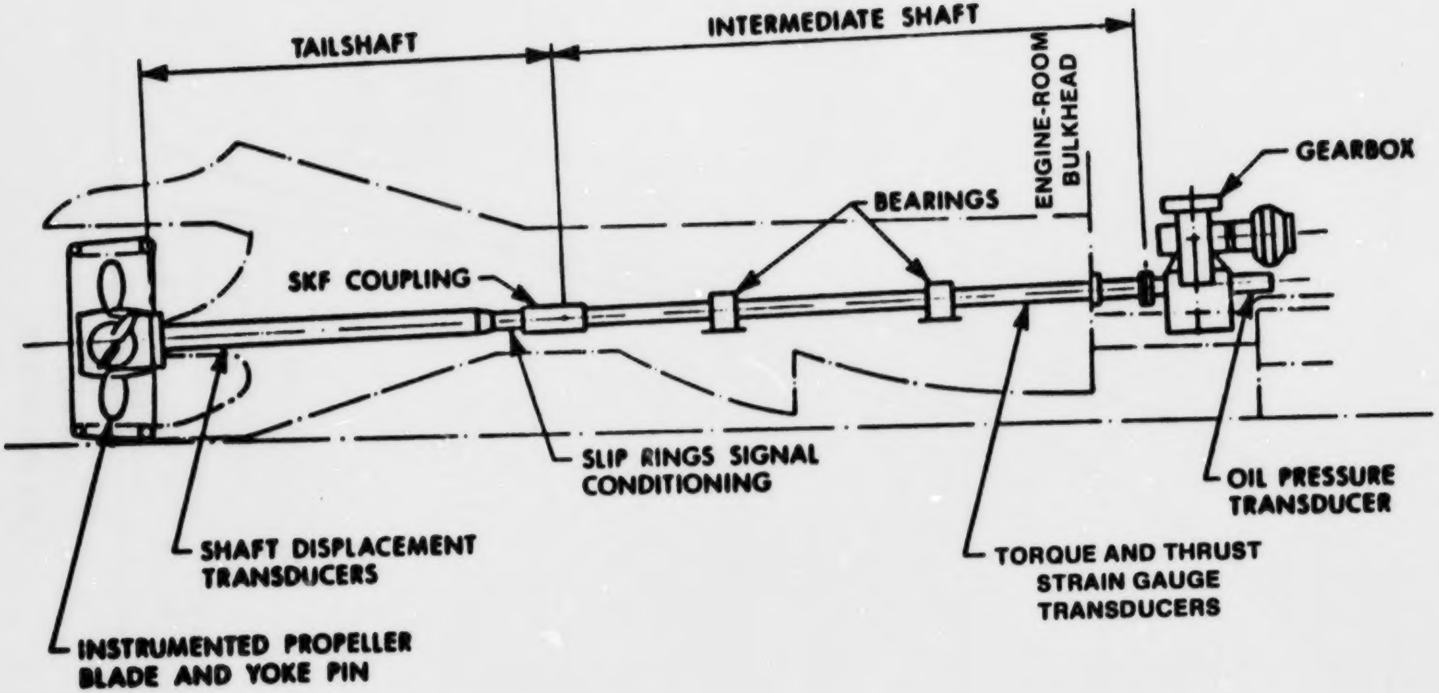
LENGTH OVERALL	82·800 METRES
LENGTH DISPLACEMENT	78·000 M
LENGTH ICEBREAKING WL.	79·125 M
BREADTH EXTREME (OVER FENDERS)	19·016 M
BREADTH MOULDED	18·000 M
DEPTH MLD. TO FOCSLE DECK	10·500 M
DEPTH MLD. TO MAIN DECK	7·500 M
SUMMER DRAFT MLD	5·668 M
ICEBREAKING DRAFT	5·500 M
FRAME SPACING	2·000 M
DEADWEIGHT (MAXIMUM)	2690·4 TONNES
PORT OF REGISTRY	EDMONTON, ALBERTA
REGISTERED TONNAGE	1501·49
OFFICIAL NUMBER	801810

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
M.V. ROBERT LEMEUR GENERAL ARRANGEMENT

FIGURE No. 3.1


TAILSHAFT
INTERMEDIATE SHAFT
ENGINE-ROOM BULKHEAD
GEARBOX
BEARINGS
SKF COUPLING
SLIP RINGS SIGNAL CONDITIONING
OIL PRESSURE TRANSDUCER
SHAFT DISPLACEMENT TRANSDUCERS
TORQUE AND THRUST STRAIN GAUGE TRANSDUCERS
INSTRUMENTED PROPELLER BLADE AND YOKE PIN

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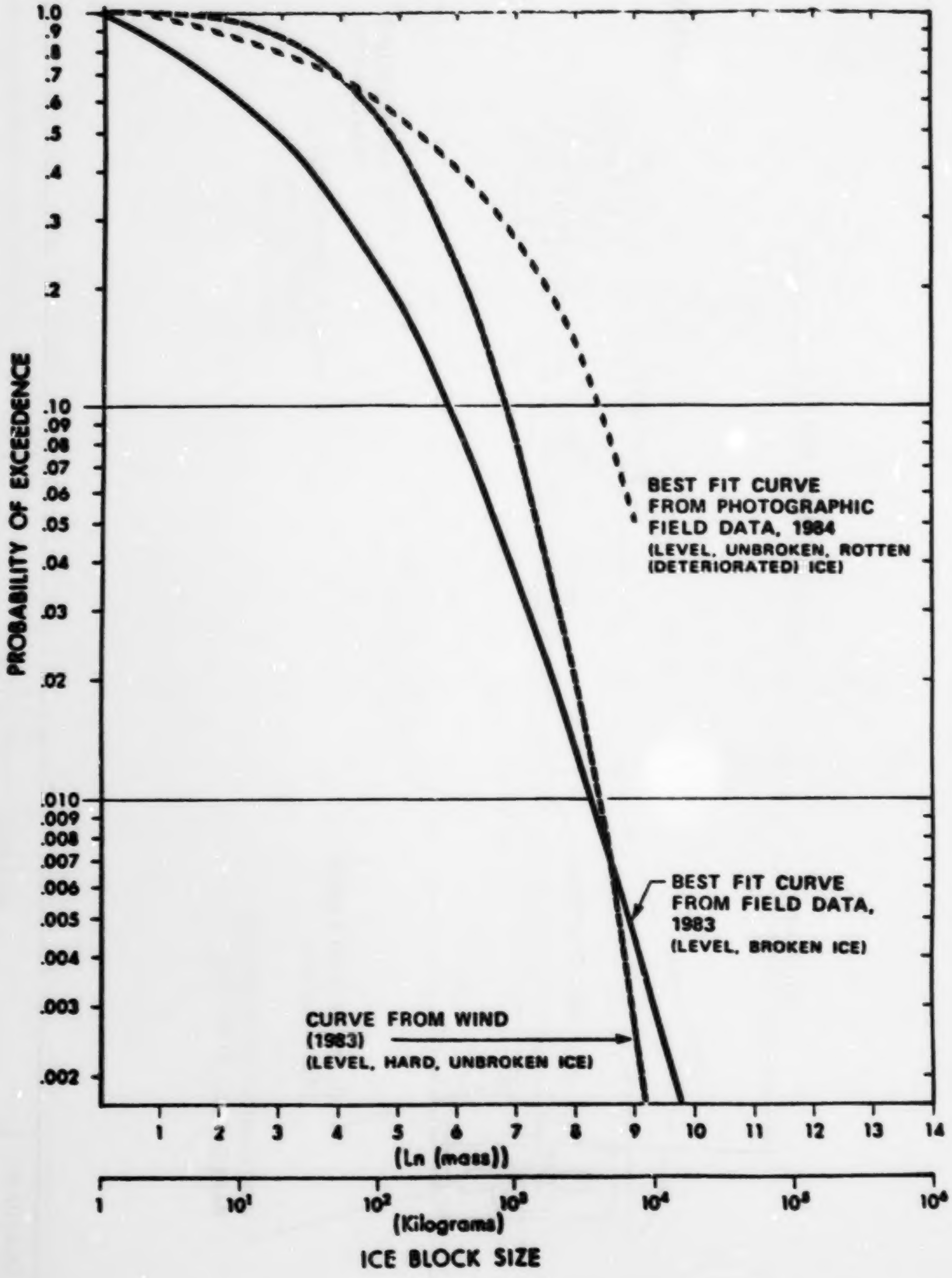
MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE: LOCATION OF TRANSDUCERS
STARBOARD SHAFT

FIGURE No. 3-2



CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: EXCEEDENCE PROBABILITY OF BLOCK SIZE DISTRIBUTION FIGURE No. 3-3

4. ANALYSIS OF THE FIVE-DAY TEST DATA

4.1 Software

The first task executed in the post-data gathering stage was to write software for the transfer of the 343 data disks containing all of the interaction events to Nine-Track IBM-compatible tapes. Two sets of tapes were produced and stored.

The second task was the writing of two programs for the analysis of the 343 events. One program, called "ANALYSE4_1", is used to manipulate the raw data from:

- 20 Dynamic blade calibrations.
- 343 Tests Disks.
- 6 Nine-Track back-up data tapes.

The following blade related quantities can be calculated from the raw data:

- Out-of-plane bending moment.
- Out-of-plane blade force.
- Spindle torque.
- Radial and circumferential location of the load on the propeller blade.

The channels of data available using the "ANALYSE4 1" program are listed in Table 4.1-1.

The second program used for data analysis, "STATALYSE8", is used to produce plots from the statistics. Channels available for the test results' statistical manipulation are listed in Table 4.1-2.

The 343 events were then scrutinized for omissions and calibration errors. Transmission errors and software errors were identified and corrected. It is believed that the data is now 90% - 95% debugged.

4.2 Event Categorization

After debugging the data, the preliminary analysis of the data was carried out. Firstly, the 343 events were categorized into:

- No apparent events
- Isolated ice/propeller interaction
- Ice milling
- Nozzle blockage

CHANNEL LISTINGS FOR ACTUAL TEST DATA

#	CHANNEL DESCRIPTIONS	UNITS	COMMENTS
	ACQUIRED CHANNELS		
1	CENTRE BENDING	MPa	POS SIG FOR TIP BENDING FORWARD
2	TRAILING EDGE TORQUE	MPa	POS SIG FOR TRAIL. EDGE BENDING FWD
3	LEADING EDGE BENDING	MPa	POS SIG FOR TIP BENDING FORWARD
4	CENTRE TORQUE	MPa	POS SIG FOR TRAIL. EDGE BENDING FWD
5	TRAILING EDGE BENDING	MPa	POS SIG FOR TIP BENDING FORWARD
6	LEADING EDGE TORQUE	MPa	POS SIG FOR TRAIL. EDGE BENDING FWD
7	SLIDING BLOCK FORCE	kN	POS SIG FOR TRAIL. EDGE BENDING FWD
8	SHAFT THRUST	kN	POS SIG IS SHAFT IN TENSION
9	SHAFT TORQUE	kN.m	POS SIG IS ENGINE DRIVING SHAFT
10	SERVO OIL PRESSURE	bar	POS CHANGE INCREASES PITCH ANGLE
11	AFT TOPE PROBE	mm	POS CHANGE, INCREASING SEPARATION
12	FWD PORT PROBE	mm	POS CHANGE, INCREASING SEPARATION
13	FWD PORT PROBE	mm	POS CHANGE, INCREASING SEPARATION
14	FWD STRB PROBE	mm	POS CHANGE, INCREASING SEPARATION
15	SHAFT RATE PULSE	volt	TEN O'CLOCK LOOKING FORWARD, 1/REV
16	PROPELLER PITCH	deg	POS SIGNAL, AHEAD PITCH
17	SHIP SPEED	m/s	ABSOLUTE VALUE OF VELOCITY
18	RUDDER ANGLE	deg	POS SIG IS STBD.
	CALCULATED QUANTITIES		
19	BENDING MOMENT	kN.m	POS SIG FOR TIP BENDING FORWARD
20	SPINDLE TORQUE	kN.m	POS SIG FOR TRAIL. EDGE BENDING FWD.
21	FORCE	kN	POS SIG FOR TIP BENDING FORWARD
22	RADIAL LOCATION	m	DISTANCE FROM BLADE ROOT, (0.37 RR)
23	CIRCUMFERENTIAL LOCATION	m	DISTANCE FROM BLADE C.L., LE IS POS
24	BENDING MOMENT (FILTERED)	KN.m	POS SIG FOR TIP FORWARD
25	SPINDLE TORQUE (FILTERED)	KN.m	POS SIG FOR TRAIL. EDGE BENDING FWD
26	FORCE (FILTERED)	kN	POS SIG FOR TIP BENDING FORWARD
27	RADIAL LOCATION (FILTERED)	m	DISTANCE FROM BLADE ROOT, (0.37 RR)
28	CIRCUMFERENTIAL LOCATION (FILTERED)	m	DISTANCE FROM BLADE C.L., LE IS POS
29	AFT HORIZONTAL	mm	POS SIG IS SHAFT TO STBD.
30	AFT VERTICAL	mm	POS SIG IS SHAFT TO TOP
31	FORWARD HORIZONTAL	mm	POS SIG IS SHAFT TO STBD
32	FORWARD VERTICAL	mm	POS SIG IS SHAFT TO TOP
33	FFT		FAST FOURIER TRANSFORM
34	SHAFT SPEED	RPM	ALWAYS POSITIVE
35	FILTERED		ANY DESIRED CHANNEL

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MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
CHANNELS AVAILABLE IN THE "ANALYZE 4– 1 PROGRAM

TABLE 4.1 - 1

CHAN #	CHANNEL DESCRIPTIONS	UNITS	COMMENTS
1	BLADE CENTRE BENDING	MPa	POS SIG FOR TIP BENDING FORWARD
2	BLADE TRAILING EDGE TORQUE	MPa	POS SIG FOR TRAIL. EDGE BENDING FWD
3	BLADE LEADING EDGE BENDING	MPa	POS SIG FOR TIP BENDING FORWARD
4	BLADE CENTRE TORQUE	MPa	POS SIG FOR TRAIL. EDGE BENDING FWD
5	BLADE TRAILING EDGE BENDING	MPa	POS SIG FOR TIP BENDING FORWARD
6	BLADE LEADING EDGE TORQUE	MPa	POS SIG FOR TRAIL. EDGE BENDING FWD
7	SLIDING BLOCK FORCE	kN	POS SIG FOR TRAIL. EDGE BENDING FWD
8	SHAFT THRUST	kN	POS SIG IS SHAFT IN TENSION
9	SHAFT TORQUE	kN.m	POS SIG IS ENGINE DRIVING SHAFT
10	SERVO OIL PRESSURE	bar	POS CHANGE INCREASES PITCH ANGLE
11	LOC. and DIR. OF MAX FORCE	m	0=ROOT 0.945=TIP;.691=LE 0=CL CIRC.
12	AFT TOPE PROBE	mm	POS CHANGE, INCREASING SEPARATION
13	FUEL RACK	mm	POS CHANGE, INCREASING FUEL
14	TYPE OF INTERACTION		0=N/E; 1=ISOLATED; 2=MILL.; 3=BLOCKAGE
15	INTER. #, ICE or WATER, DIR.		#:0=WATER, 1=ICE: -1=AST, 0=STOP, 1=AHD
16	PROPELLER PITCH	deg	POS SIGNAL, AHEAD PITCH
17	SHIP SPEED	m/s	ABSOLUTE VALUE OF VELOCITY
18	RUDDER ANGLE	deg	POS SIG IS STBD.
19	BLADE BENDING MOMENT	kN.m	POS SIG FOR TIP BENDING FORWARD
20	BLADE SPINDLE TORQUE	kN.m	POS SIG FOR TRAIL. EDGE BENDING FWD.
21	BLADE FORCE	kN	POS SIG FOR TIP BENDING FORWARD
22	SHAFT SPEED	RPM	ALWAYS POSITIVE
23	BLADE START PEAK & DURATION	deg	0 DEG. TOP 90 is INBOARD, SINGLE BL
24	TQ. ENEG. & DUR.; FORCE AREA		INT. ENEG KJ; DUR. s: FORCE AREA kN.s
25	THRUST ST. PK. & END TIME	s	THRUST EVENT, AUTO CHOOSEN
26	THRUST ST. PK. & END THRUST	kN	THRUST EVENT, AUTO. CHOOSEN
27	THRUST ST. PK. & END TORQUE	kN.m	THRUST EVENT, AUTO. CHOOSEN
28	TORQUE ST. PK. & END TIME	s	TORQUE EVENT, AUTO. CHOOSEN
29	TORQUE ST. PK. & END THRUST	kN	TORQUE EVENT, AUTO. CHOOSEN
30	TORQUE ST. PK. & END TORQUE	kN.m	TORQUE EVENT, AUTO. CHOOSEN

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MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE: LISTING OF DESCRIPTIONS OF CHANNELS OF DATA AVAILABLE ON STATISTICS DISK

TABLE 4.1-2

4.3 Description Of A Single Event

A detailed description of one test was carried out in order to confirm the correct signal response and the cross-correlations between interaction variables, like shaft torque, pitch angle, spindle torque and others.

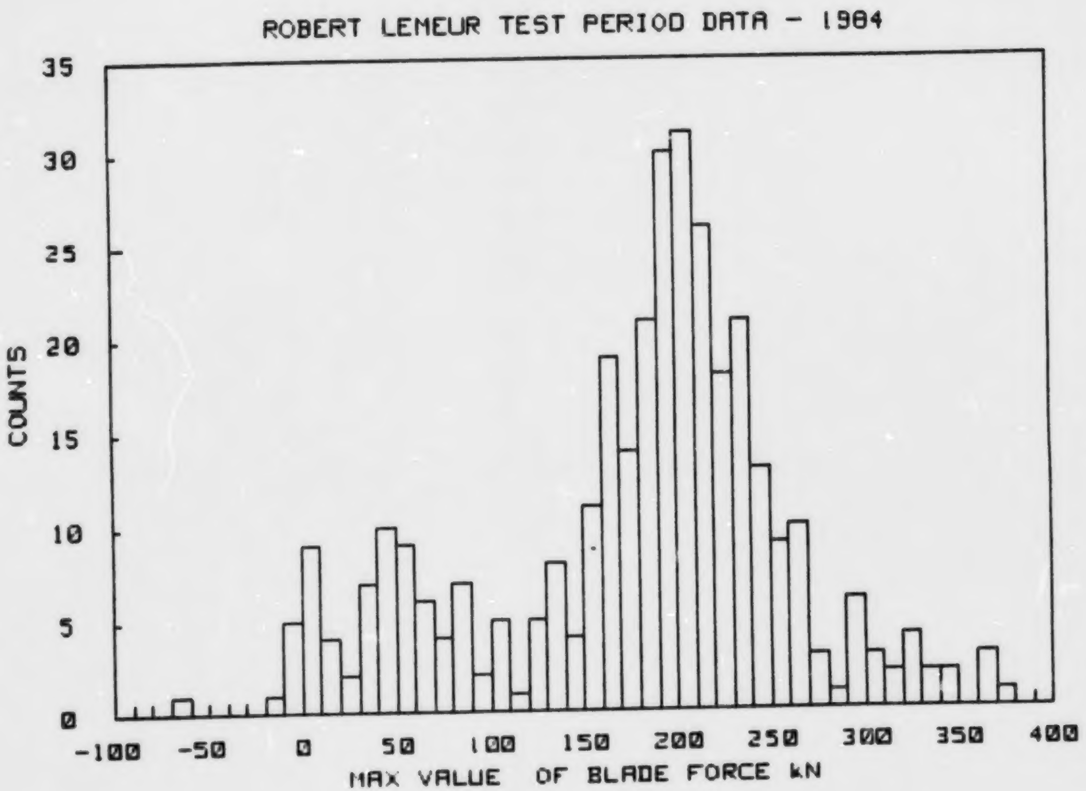
4.4 Analysis Of Blade Force

Detailed analysis of the blade force was then carried out. Hydrodynamic load component, ice-induced loads, their magnitudes, directions and points of application on the blade were determined. A summary of the main findings is given below:

- Maximum recorded blade load was 375 kN, which is 5.3 times higher than the calculated hydrodynamic steady state load at bollard condition. (see Figures 4.4-1 and 4.4-2).
- Water/ice induced loads in blockage events are nearly as high (85%) as impact loads during the single events. (See Figure 4.4-3).
- Most of the impact forces were directed forward but some were directed aft.
- A number of events had ice force directed in the plane of the blade.
- Calculated circumferential locations of out-of-plane forces are about the centerline of the blade. This maybe due to inability to account for the in-plane component of the force.
- Large impact forces are located on the outer half of the blade, i.e. relative radius (r/R) = 0.84.
- The magnitude of the blade force decreases with an increase in the distance between the shaft centerline and the point of load application.
- An average duration of the blade impact was 0.063 seconds.
- The higher the impact forces, the shorter the durations of impacts.
- Small impulses are associated with high impact forces.
- Small ice blocks hitting the blade were the cause of the highest blade forces recorded during the tests.

An influence of various parameters on the magnitude of blade force was investigated. The results are given below:

-RPM: The relationship between shaft RPM and the



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TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 340
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:177.37
AND ITS STANDARD DEVIATION IS:82.413

ALL DATA USED
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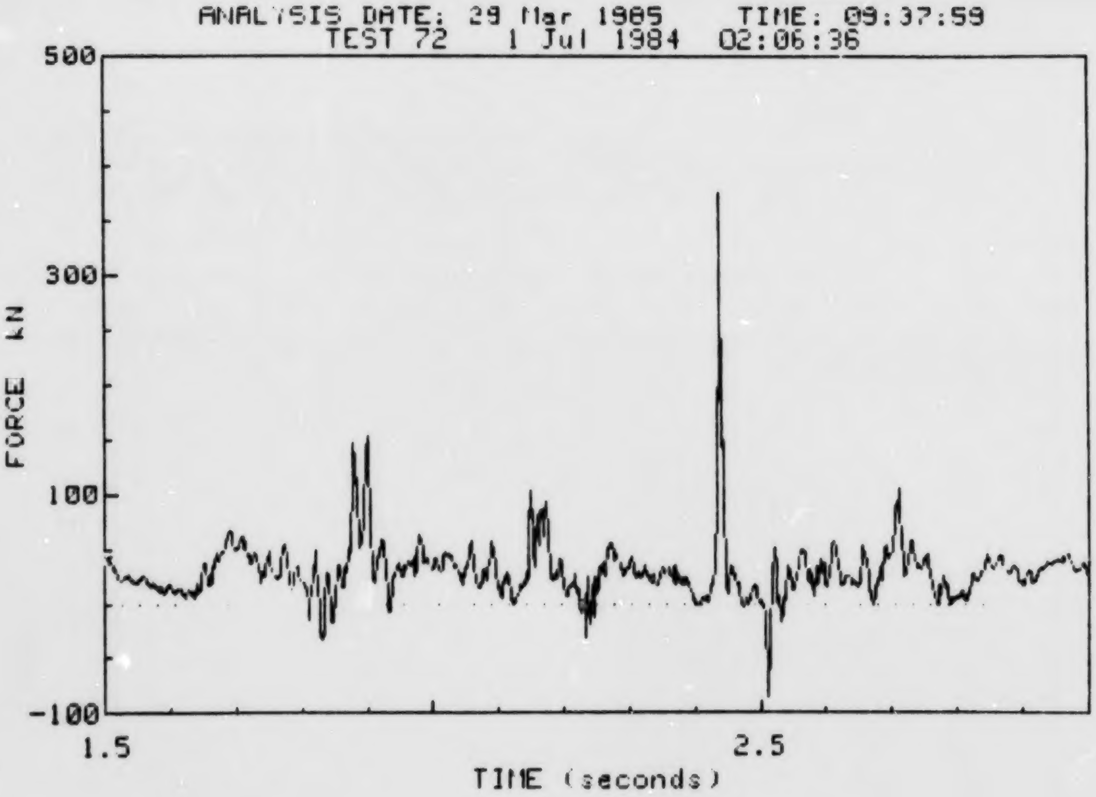
CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **STATISTICS OF THE MAXIMUM VALUE OF BLADE FORCE**
		FIGURE No. 4.4-1

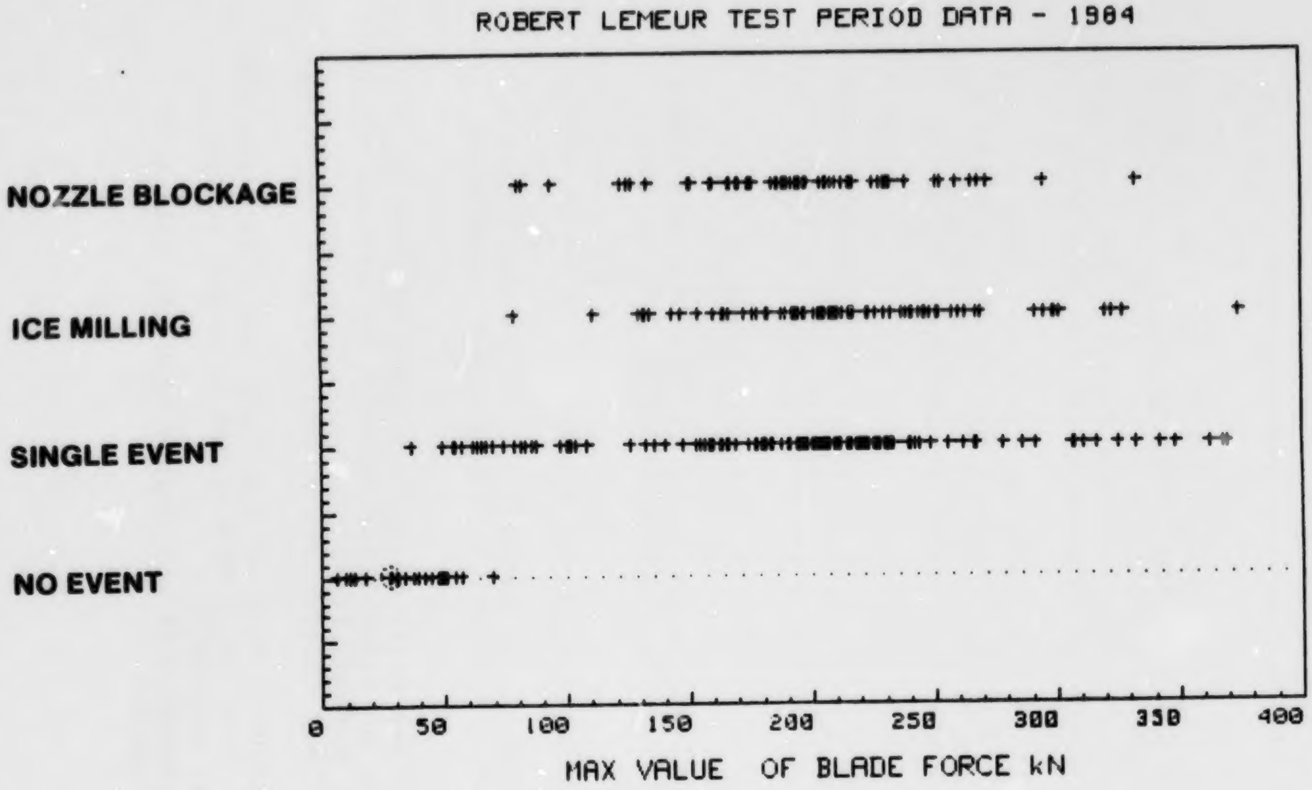


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **TIME HISTORY OF THE BLADE FORCE IN EVENT #72**

FIGURE No. 4.4-2



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 321

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE OF LOC. and DIR. OF MAX FORCE > 0

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: DEPENDANCE OF THE MAXIMUM FORCE ON THE TYPE OF INTERACTION
		FIGURE No. 4.4-3

maximum blade force during an event is shown in Figure 4.4-4. Increase of RPM leads to an increase of the impact forces. This can be expressed by the equation:

$$\text{Max Blade Force} = 80\,(\text{RPM} - 160)^{1/4} \quad \text{For RPM} > 160$$

This equation reflects the test data only and is not intended to represent the general trend. Low values of ice force at 160 RPM reflects lack of data points at that shaft speed. Varying the pitch settings does not alter this tendency.

-Propeller Pitch: Within 30% of the average pitch setting, no influence of the pitch setting on the magnitude of blade force was detected. Forces on the blade dropped drastically with the decrease of pitch below 16°. Negative pitch produced very low impact forces.

-Ship Turning/Rudder Angle: When the ship is turning to port, higher frequency of interactions and higher impact forces are observed on the starboard propeller, than when the rudder is amidship or to starboard.

-Ship Speed: There is no correlation between ship speed and the magnitude of the maximum blade force. Hydrodynamic load on the blade can be expressed as:

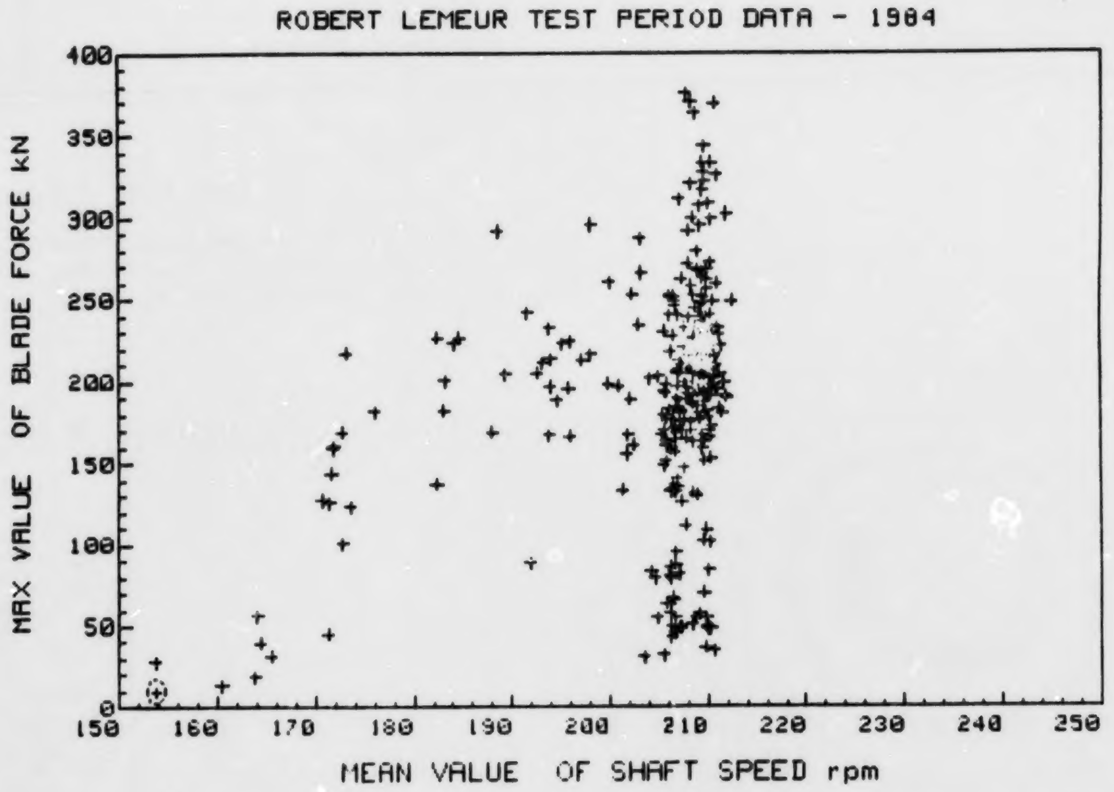
$$(BF)_{hydro} = 51.5 - 2.92 \times \text{ship speed},$$

where the blade force is in kN, and the ship speed is in m/sec. The above formula is valid for the test conditions only.

4.5 Analysis of Shaft Torque

A histogram of the maximum values of shaft torque during each event is shown in Figure 4.5-1. Important findings were:

- The maximum shaft torque recorded was 305 kN.m.
- There is no correlation between the maximum torque and the maximum thrust.
- The maximum torques are associated with low thrust values.
- The maximum torque on one blade was five times the maximum continuous hydrodynamic torque on the blade at bollard.
- Shaft torque does not change with the change of rudder angle.



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DATA SATISFIED THE FOLLOWING TEST(S)

MEAN VALUE OF SHAFT SPEED > 100 rpm
AND
MEAN VALUE OF PROPELLER PITCH > 0 deg

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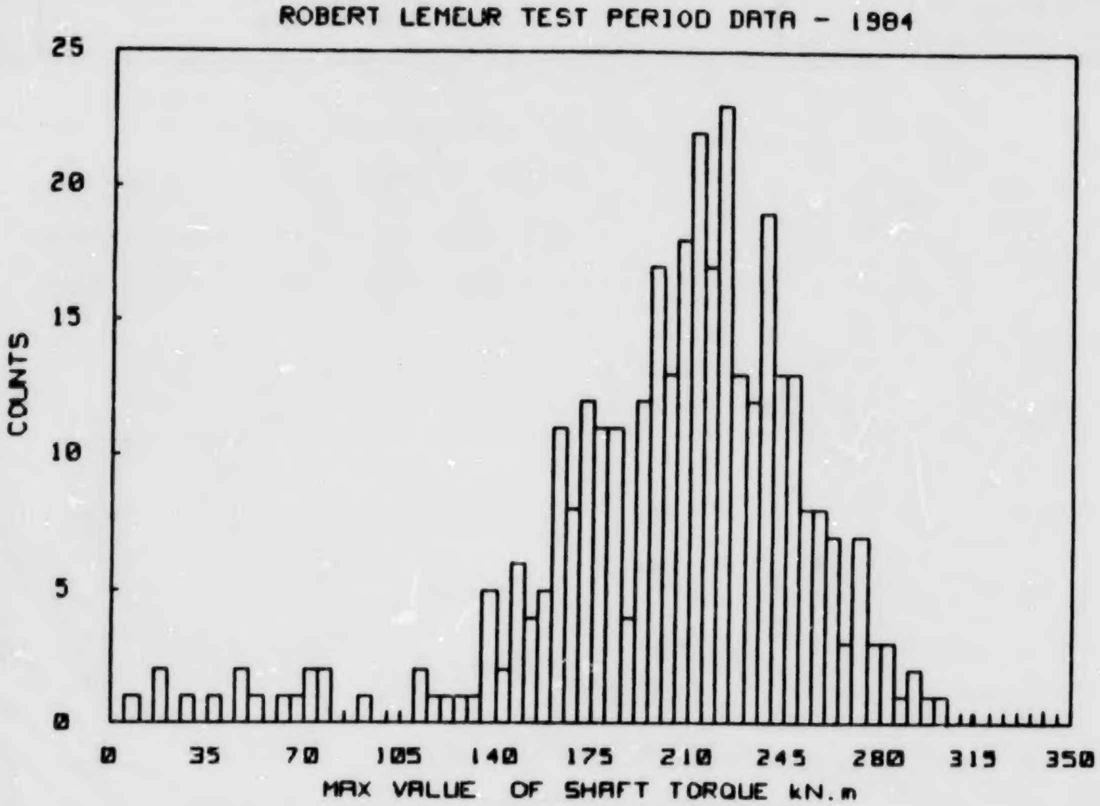
MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: INFLUENCE OF SHAFT RPM ON THE MAXIMUM BLADE FORCE, FOR AHEAD PITCH ANGLES

FIGURE No. 4.4-4



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AND ITS STANDARD DEVIATION IS:49.005

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: HISTOGRAM OF MAXIMUM VALUES OF SHAFT TORQUE FIGURE No. 4.5·1

4.6 Analysis of Shaft Thrust

Histograms of the maximum value of shaft thrust (shaft in tension) and minimum value of shaft thrust (shaft in compression) during each event are shown in Figures 4.5-2 and 4.5-3. Important findings were:

- The mean value of shaft thrust in open water transits can be expressed as:
  - Thrust = 283 - 9.5 V,

  where thrust is in kN and V is in m/s.
- During the ice impact events, thrust fluctuations are large, in both ahead and astern directions.
- The maximum excursions of shaft thrust were 4.6 times the bollard thrust in ahead direction and 1.7 times in astern direction this ratio requires further verification due to the drift of shaft thrust signal.
- When operating in ice covered waters, the mean thrust level during events rose to 2.2 times (this number needs further verification) the hydrodynamic bollard thrust level, and:
- Mean shaft thrust increases with the rudder turned to port.

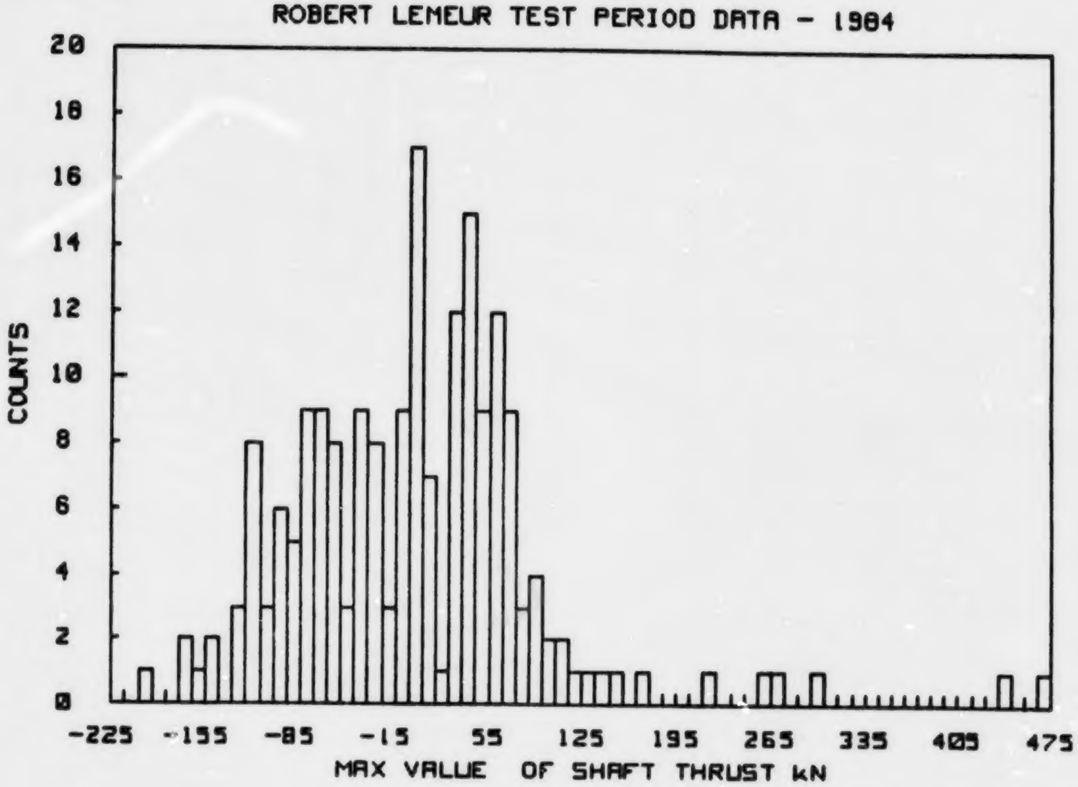
An investigation of the event durations revealed that:

- High impact forces are of short duration.
- The average impact force duration is equal to the time of the blade pass.
- Longer impact durations correspond to lower blade forces.

An analysis of the blade position at the instant of first contact with ice led to the following conclusions:

- The presence of a skeg in the front of the nozzle has pronounced influence on the position of ice contacting propeller blade (a shadow is created where no ice is present).
- Maximum interaction with ice occurred at approximately 50° and 240° of blade position measured counterclockwise from the 12 o'clock position.
- For the propulsion shafting strength calculations, blade force should be applied at approximately 80° and 270°.
- With such positions of force application, the shaft excursions in the horizontal plane should be more pronounced than those in the vertical plane.

An analysis of the blade displacements under the load showed that the ice impact induced vibrations of the blade in water lead to an increase of the average thrust.



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 193
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:.42901
AND ITS STANDARD DEVIATION IS:93.105

ALL DATA USED

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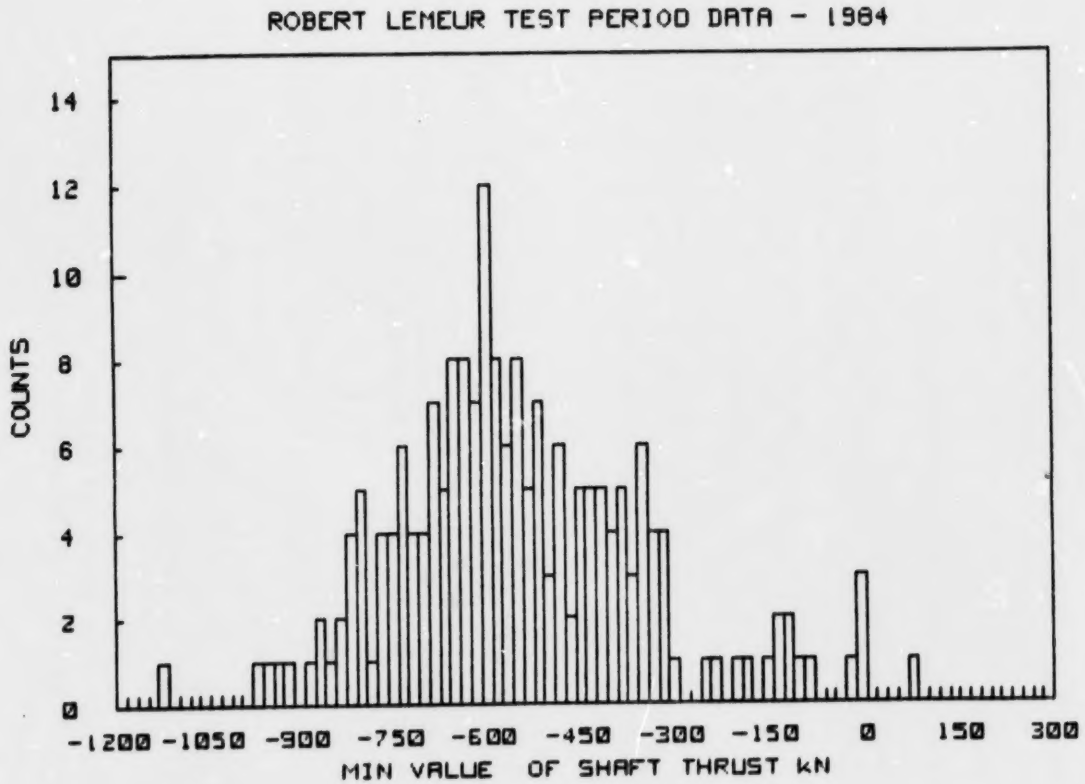
MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: HISTOGRAM OF THE MAXIMUM VALUES OF SHAFT THRUST

FIGURE No. 4.5-2



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 193
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:-556.7
AND ITS STANDARD DEVIATION IS:202.98

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:**	**HISTOGRAM OF THE MINIMUM VALUES OF SHAFT THRUST**
		FIGURE No. 4.5-3	

Water damping of the vibrations was found to be high (25% of the critical damping) and the calculated added mass coefficient is 4. The dynamic magnification of the blade response was found to be an important issue when scaling the test results. For the highest loads, which are of very short durations, the static load interpretation technique underestimates the forces.

The maximum blade bending moment recorded during the tests was 310 kN m. This moment lead to the blade stresses exceeding the yield stress in compression.

4.7 Comparison With Theoretical Model

A comparison of the data with the analytically derived formulations showed that the analytical model was too specific and the majority of its components were not verifiable. Only the large excursions of basic parameters, like RPM, pitch etc., lead to the significant changes of blade forces and bending moments. Therefore a "lumped-parameter" model was evolved, based on the data obtained, with the previously derived analytical model serving as a back-up, and explanatory tool for future use. The proposed model (valid for the data collected only) is summarized below:

-Blade Force: Maximum blade force = -80 + 0.16 * shaft power (force in kN, power in kW). The direction of force application was perpendicular to the blade chord at r/R= 0.47. The location of force application was at r/R = 0.7 and 1/2 way between the leading edge and the centre of the blade. This statement needs former verification. The duration of load application was equal to the time needed to rotate the blade through the distance equal to the blade chord at the point of load application, at rated RPM.

-Blade Bending Moment: The maximum blade bending moment [$(BBM)_{MAX}$] at the blade root (r/R = 0.37) is:
$(BBM)_{MAX}$ = Shaft kW/11
This is the total bending moment composed of the hydrodynamic and ice induced loads.

-Shaft Torque: The maximum shaft torque is twice the bollard shaft torque, and its duration is 0.55 seconds**.

** Note that all of the durations given in this report are the response durations and are not necessarily the durations of the applied load.

-Shaft Thrust: The maximum shaft thrust is 4.6 times the bollard thrust, and its duration is 0.05 seconds. This number is subject to further verification. The short duration of the peak thrust is due to the high stiffness of the shaft in the longitudinal direction which leads to the high frequency vibratory response.

-Blade Model: The comparison of the stresses calculated by using a tapered beam model and those measured during the calibration tests showed good agreement between the two. The ratio of compressive to tensile stresses at r/R = 0.6 is 1.48. This means that the neutral axis is closer to the blade pressure side and the higher stresses are generated at the suction side of the blade section.

4.8 Shaft Torque and Thrust Models

The above summarized investigations and modelling work was carried out using "raw" data from the propeller and shafting gauges. The question of predicting the ice forces from the shaft response only, was addressed by building a three degree of freedom lumped mass longitudinal and torsional model of shafting system response to the thrust and torque impulse, respectively. Using torque and thrust gauges response as calibrating functions, the input thrust and torque functions were derived by using trial and error method. The input functions were then compared to the propeller blade gauges signals to assure their compatibility. The main conclusions from this modelling were:

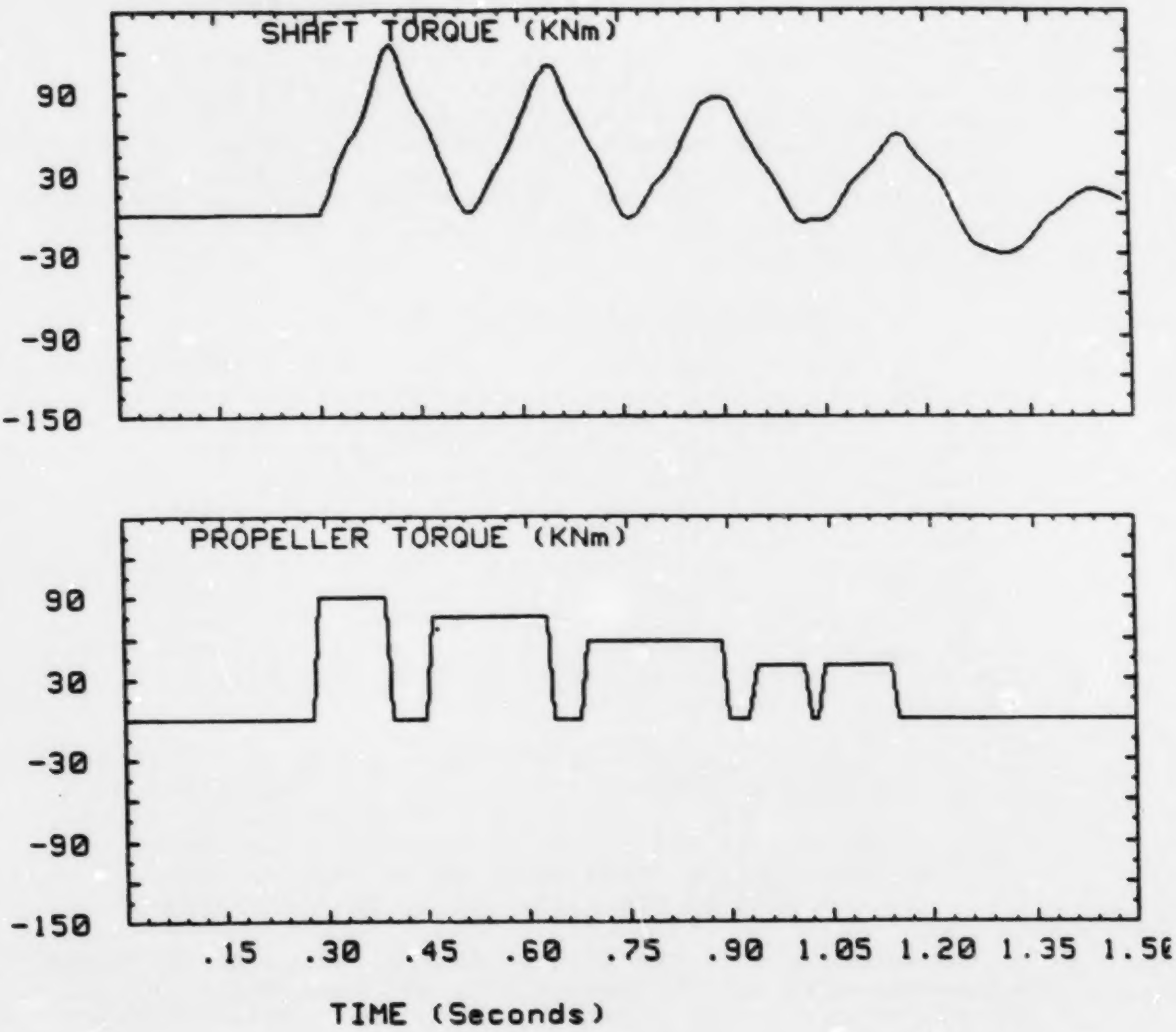
- Longitudinal and torsional models of the shafting system are suitable tools for the prediction of ice induced forces acting on the propeller blades.
- The models can be used to estimate the number of blades interacting with ice as well as the direction of the force acting on the blades.

An example of the theoretical propeller blade torque which produces a shaft torque response similar to an actual event, at the location of the shaft torque strain gauge sensors is shown in Figure 4.8-1.

An example of the theoretical propeller thrust which produces a shaft thrust response similar to an actual event at the location of the shaft thrust strain gauge sensors is shown in Figure 4.8-2.

4.9 Analysis Of Yoke Pin Model

The yoke-pin model was re-evaluated after the



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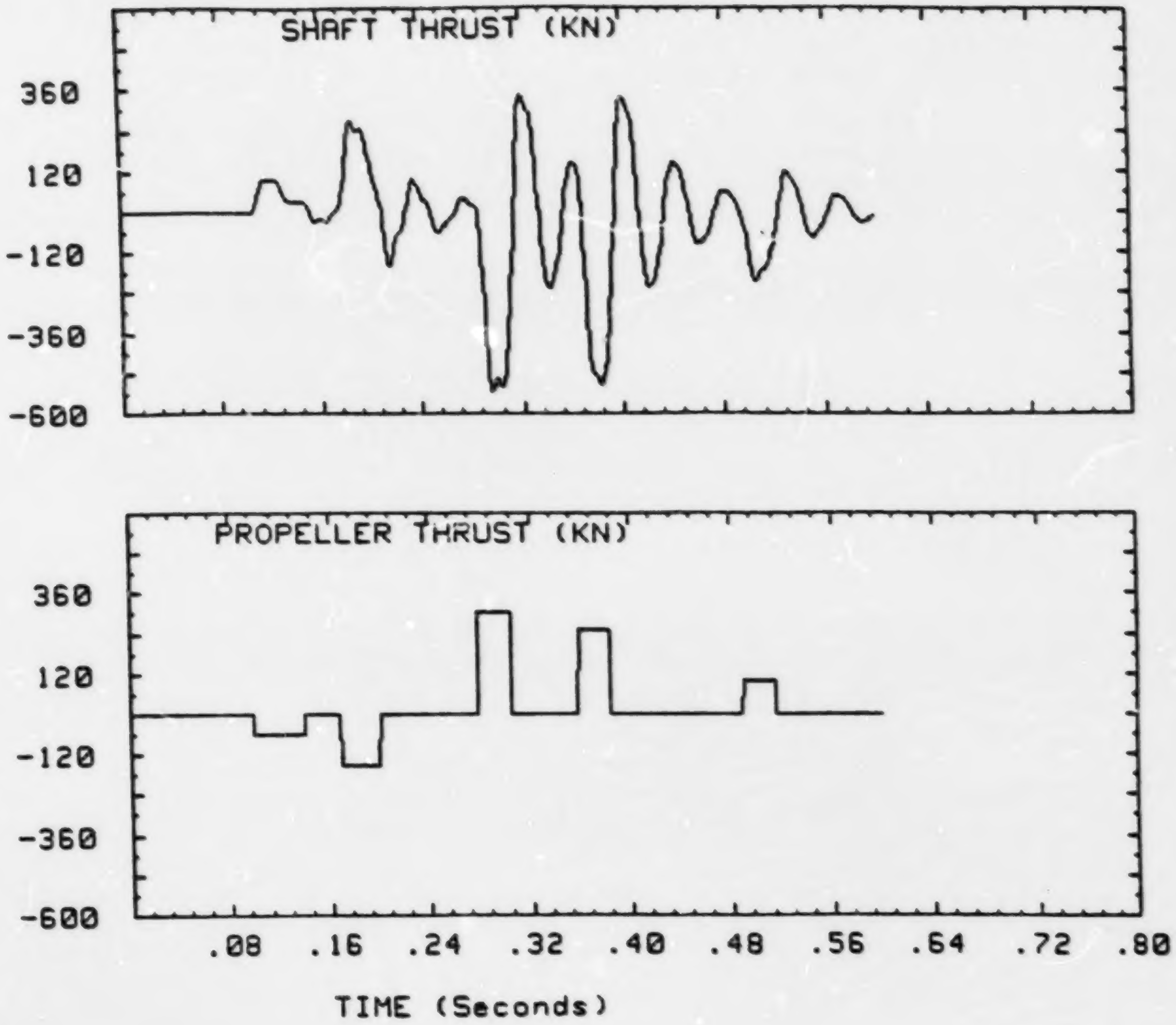
MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
ESTIMATED CHANGE IN PROPELLER TORQUE FOR TEST 117

FIGURE No. 4.8-1



PLOTS OF THRUST FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM MODEL

TEST 72
ANALYSIS DATE: 85/03/14

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MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE: CALCULATED THRUST RESPONSE FOR A SERIES OF SHORT IMPACTS, TEST 72

FIGURE No. 4.8-2

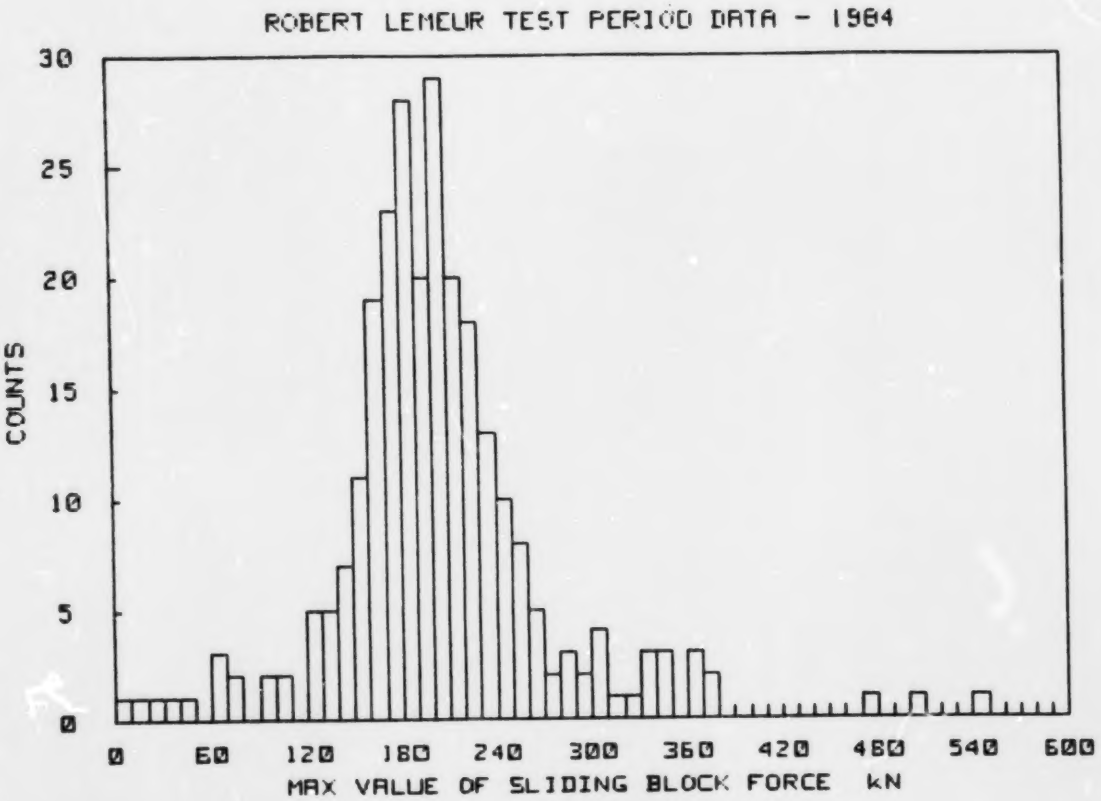
recalibration of the yoke sliding block. A histogram of the maximum sliding block force during the events is shown in Figure 4.9-1. The analysis of the sliding block, spindle torque and servo oil pressure sensors showed that:

> Due to friction in the pitch changing mechanisms, the maximum excursions of the blade spindle torque and sliding block loads cannot be measured accurately with the servo oil pressure.
>
> The friction in the blade carrier system limits the load on the sliding block to 90% of the value calculated assuming no friction.

4.10 Analysis Of The Shaft-Proximity Probes

The analysis of the shaft-proximity probes data mounted at the stern-tube bearing was carried out. Only limited amount of the data was available due to probe failures. The available data is shown in Figure 4.10-1. The main conclusions from the analysis are summarized below:

- There is a greater tendency for horizontal motion than vertical motion of the shaft in the aft stern-tube bearing.
- The motion is erratic and is forced at the blade passing frequency.
- The performance of the bearing is outside of the predictive capability of the standard (steady state) hydrodynamic bearing theory.



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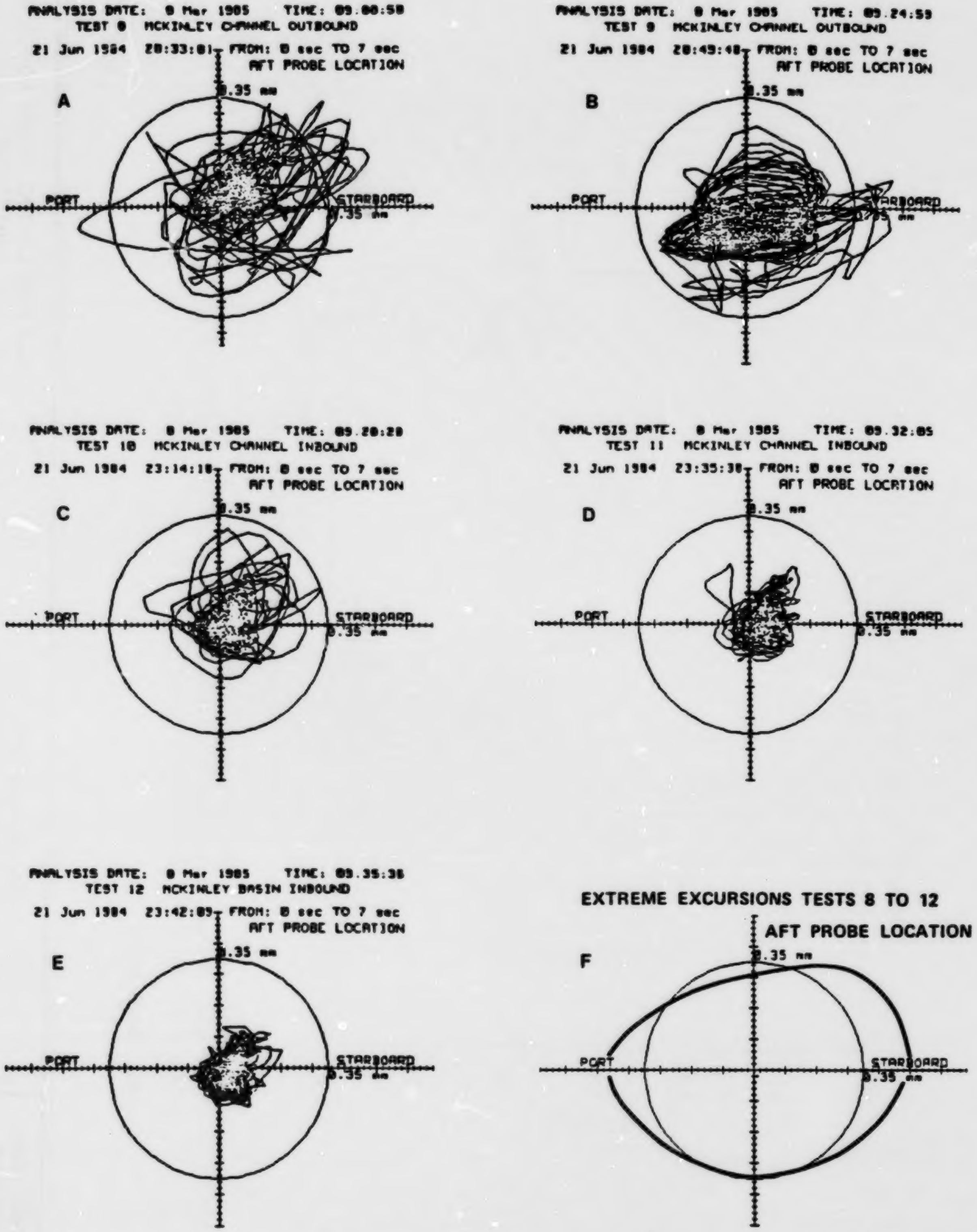
AND ITS STANDARD DEVIATION IS:67.067

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: MAXIMUM SLIDING BLOCK FORCE HISTOGRAM FIGURE No. 4.9-1



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MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE: LISSAJOUS FIGURES
FOR TEST 8 TO 12

FIGURE No. 4.10-1

5. ANALYSIS OF LONG TERM SHAFT STATISTICS

It was recognized from the onset of this project that the collection of a full season of data would be a valuable addition to the knowledge gained during the 5-day field program. Two types of recordings were gathered:

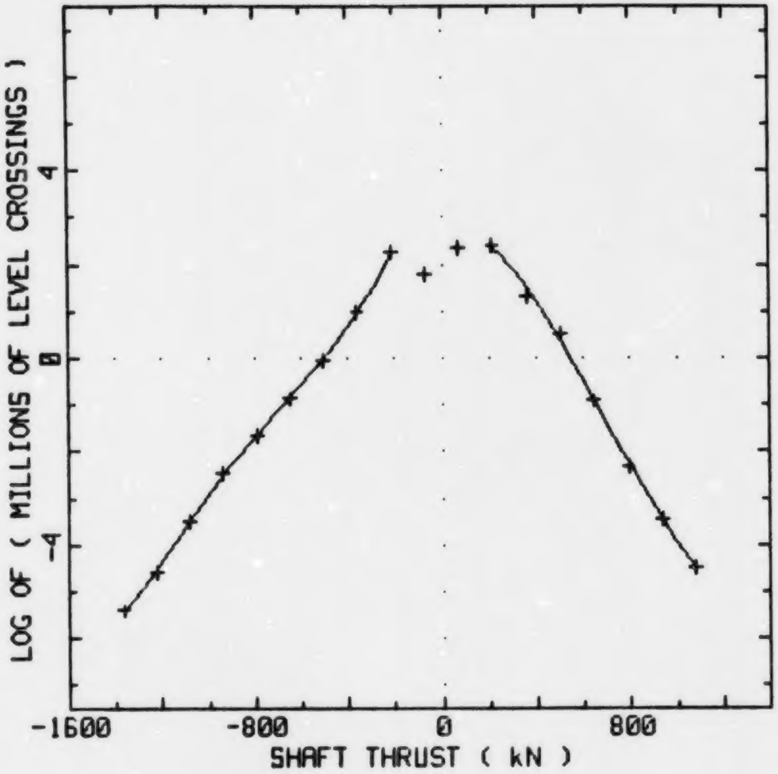
- Statistical data from torque and thrust signal.
- Sample recordings of torque, thrust and ship's speed.

The plot of the level crossing counts for the shaft thrust and torque signals for the complete season are shown in Figures 5-1 and 5-2.

When the long term shaft statistics were compared with those collected during the 5-day tests, the following relationships were established:

- Maximum shaft compression was 21% larger than the maximum recorded during the 5-day testing.
- Maximum shaft tension was 127% larger (while backing).
- Maximum shaft torque was 10% larger.

An important conclusion derived from this comparison is that the 343 events are very representative of the whole season operations, except for the astern pitch maneuvers (tension in the shaft). These events are a very close approximation of the maximum ice loads the MV Robert LeMeur encountered during the whole 1984 operating season.



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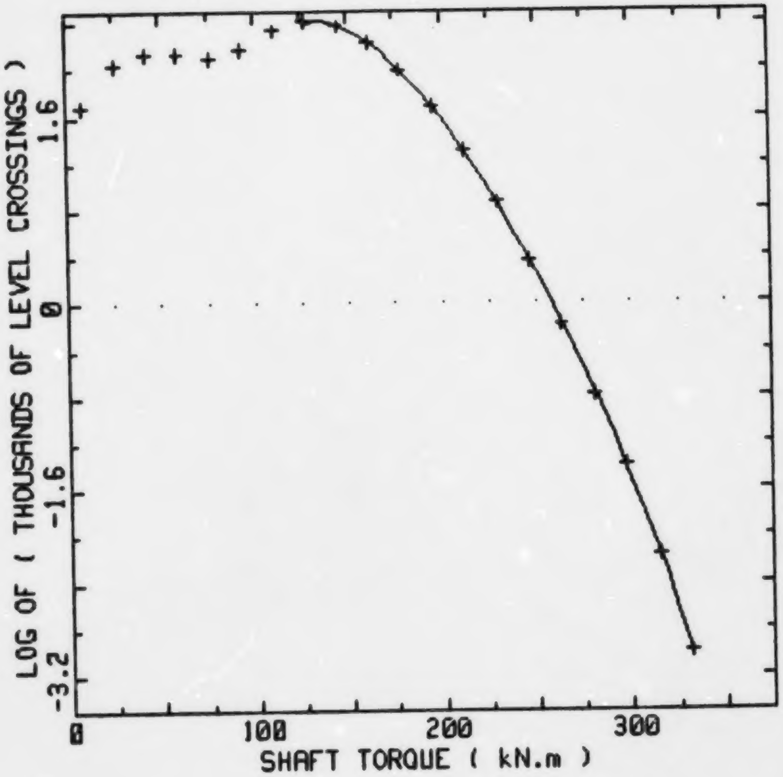
PARAMETERS

TITLE: LEVEL CROSSING COUNTS FOR SHAFT THRUST DURING 1984 SEASON

FIGURE No. 5-1



EQUATION OF PLOTTED LINE

LOG (Y/1E3) = -2.212665E-09 + X^4 + 2.099041E-06 + X^3
-8.340003E-04 + X^2 + 1.309154E-01 + X
-4.487115

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MEASUREMENT OF ICE
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PARAMETERS

TITLE: LEVEL CROSSING COUNTS FOR SHAFT TORQUE DURING 1984 SEASON

FIGURE No. 5-2

6.0 RECOMMENDATIONS

6.1 General

Preliminary data analysis has indicated significant departure from the previous understanding (based on the open propeller-ice interaction) of ice interaction phenomena for a shrouded propeller. The issue is of such importance as to warrant more in-depth analysis in order to fully understand and justify the findings. The analytical effort should be continued without a break. The timing is opportune because of the availability of the principle participants from the current study.

6.2 Blade

Further study is necessary to quantify the influence of dynamic aspects of ice interaction with a blade.

The influence of water on maximum blade loading must be analysed from the test data in order to allow scaling factors to be established for application to other vessels.

Life cycle fatigue analysis of the blade and hub components undertaken in order to predict the onset of fatigue failure.

6.3 Bearing

The test results require further study to determine:

- Scaling factor and zero offsets for the traces.
- Misalignment data.
- Acceleration forces created by radial displacement of the shaft.

A MV Robert LeMeur bearing model should be developed capable of substantiating, as far as possible, the findings of these field results.

6.4 Shaft System

The development of more detailed models to incorporate combined ice-propeller interaction and machinery control parameters is recommended. These models should eliminate the approximations made with the existing models, and be made general enough for applications to other vessels.

- A statistical analysis be preformed on the thrust and torque estimates from the above models.
- A series of propeller torque and thrust input functions during ice interaction be generated for design purposes.
- A study be done on the feasibility of incorporating mathematical models that predict propeller loads from shaft measurements only, for use in regulations and preventative maintenance programs, for propulsion systems operating in ice.

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TP 6839E
MEASUREMENT OF ICE/PROPELLER INTERACTION PARAMETERS - MV ROBERT LEMEUR
MAIN REPORT

PREPARED FOR THE TRANSPORTATION
DEVELOPMENT CENTRE

BY: J. DUFF
K. KIRBY
V. LASKOW

CANADIAN MARINE DRILLING LTD.
CALGARY, ALBERTA
AUGUST, 1985

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of Transport Canada.

The contractor and sub-contractors assume no responsibility for any subsequent use of the information contained in this report.

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See also: "Measurement of Ice/Propeller Interaction Parameters" Engineering & Field Tests : TP 6842E
Supplementary Analyses: TP 6841E

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I.M. Bayly

17. Abstract

This report documents the preliminary analysis of the data collected on board the M.V. Robert LeMeur during the 1984 operating season, including five days of dedicated tests in June 1984. Analysis of the propulsion train components is performed. Propeller ice impact forces are analyzed and the response of the shafting system is determined. A model of blade-ice interaction is proposed based on the data analysis. A model of the yoke-pin and shaft response to the ice torque and thrust is also developed. Software used during data analysis is fully documented. Conclusions pertinent to regulatory purposes are derived.

18. Key Words
Ship, propellers, ice, propulsion, blade, impact, interaction

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15. Remarques additionnelles Les Annexes sont présentées séparément, TP 6840 - Voir aussi "MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS" Engineering & Field Tests TP 6842E & Supplementary Analyses TP 6841E

16. Agent de projet — CDT
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17. Résumé

Ce rapport rend compte des résultats de l'analyse préliminaire des données recueillies à bord du Robert-LeMeur au cours de la saison d'exploitation 1984, y compris les cinq journées consacrées aux essais spécialisés en juin de cette année. L'analyse a porté sur les organes de la chaîne cinématique et, notamment, sur les chocs subis par les pales d'hélice et leurs répercussions sur la ligne d'arbres. Un modèle de l'interaction glaces/pales est proposé, fondé sur l'analyse des données, ainsi qu'un modèle figurant la tenue de l'arbre et de la goupille d'accouplement au couple de torsion et à la poussée résultant de cette interaction. Les logiciels utilisés sont décrits en détail. Sont enfin présentées des conclusions intéressant la réglementation actuelle et celle à venir.

18. Mots-clés
Navire, hélice, glaces, propulsion, pales, chocs, interaction.

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The authors also wish to express their gratitude to captains and crew of the MV Robert LeMeur for their patience, help and cooperation during this research project.

SUMMARY

The objectives of the project were:

- To measure directly the magnitude and location of ice interaction forces on the blade of a controllable pitch propeller (CPP) working in a nozzle, and resultant effects in the CPP hub mechanism and on the propeller shaft.
- To record the position of the tail shaft within the stern tube bearing during heavy ice/propeller interaction.
- To make a record of the tests and results which will be adequate for the future reference and re-analysis, if desired.
- To reduce data to engineering units and to analyse data to provide a coherent picture of the ice/propeller interaction phenomena, bearing in mind the ultimate use of the data in the generation of design criteria and regulations.

The report "Measurement of Ice/Propeller Interaction Parameters - MV Robert LeMeur, Engineering and Field Tests" (Milestone 1), report documented the type and choice of instrumentation used on the MV Robert LeMeur. Milestone 1 also described the field test program and introduced a series of exploratory analytical models, developed to describe the relationship between external loads and responses in selected drive train components.

This report documents the work performed in the post-data collection phase. The objectives of this phase were:

- To prepare, preserve, and protect the test data for later use.
- To prepare software packages in a "user friendly" format for use by other research workers.
- To de-bug the data.
- To conduct a preliminary analysis of the data.
- To use the analysis to report on the following topics:

i. Ice/Propeller Interaction: To determine from the test data, the types and magnitudes of ice/propeller encounters, including hydrodynamic effects. To compare the frequency and severity of ice interactions with ship operating variables. To evaluate the Ice Interaction Models proposed in Milestone 1 and offer amended versions.
ii. Propeller blade: To observe the response of the instrumented blade to its interaction with ice, especially with reference to the effect of dynamic magnification. To evaluate the accuracy of the Simple Beam Blade Model proposed in Milestone 1.
iii. Yoke Pin: To combine the findings of the static calibrations, the field test results, and the Yoke Pin Model to determine the friction at the blade foot and its influence in attenuating load impulses from the blade to the yoke pin.
iv. Shaft: To measure the shaft torque and thrust responses during ice/propeller interactions and compare with the simple Shaft Models proposed in Milestone 1. To evaluate the possibility of substituting shaft strain-gauges for blade strain-gauges for interpreting ice loading conditions on a propulsion system over an extended period of time. To collect shaft torque and thrust fluctuations data over an operating season and determine their statistical importance.
v. Bearing: To observe the motion of the tail shaft within the stern-tube bearing and explain its significance for bearing design.
vi. Long Term Shaft Statistics: To determine how representative the 343 tests were of a complete operating season. To determine shaft torque and thrust cycles during the whole operating season for potential future use in determining propulsion train fatigue. To record sample shaft torque and thrust signals during the largest shaft torque event of the operating season.

The first task executed in the post-data gathering stage was to write software for the transfer of 343 disks of data containing all of the interaction events to

Nine-Track IBM-compatible tapes. Two sets of tapes were produced and stored.

The second task was the writing of two programs for the analysis of the 343 events. One program, called "ANALYZE4_1" is used to manipulate the new data from:

- 20 Dynamic Blade calibrations.
- 343 Tests Disks.
- 6 Nine-Track back-up data tapes.

The following blade quantities can be calculated from the raw data:

- Out-of-Plane bending moment.
- Out-of-Plane blade force.
- Spindle torque.
- Radial and circumferential location of the load on the propeller blade.

The second program used for data analysis, "STATALYZE8" is used to produce plots from the statistics. Channels available for the test statistical manipulation are listed in Table 4.1-3.

The 343 events were then scrutinized for omissions and calibration errors. Transmission errors and software errors were identified and corrected. It is believed that the data is now 90% - 95% debugged.

After debugging the data, the preliminary analysis of the data was carried out. Firstly, the 343 events were categorized into:

- No apparent events
- Isolated ice/propeller interaction
- Ice milling
- Nozzle blockage

Further a detailed description of one test was carried out in order to confirm the correct response and the cross-correlations between interaction variables, like shaft torque, pitch angle, spindle torque and others.

Detailed analysis of the blade force was then carried out. Hydrodynamic load component, ice-induced loads, their magnitudes, directions and points of application on the blade were determined. The summary of the main findings is given below:

- Maximum recorded blade load was 375 kN, which is 5.3 times higher than the hydrodynamic steady state load at bollard condition.
- Water induced loads in blockage events are nearly as high (85%) as ice impact loads.
- Most of the impact forces were directed forward but some were directed aft.
- A number of events had ice forces directed in the plane of the blade.
- Large impact forces are located on the outer half of the blade at relative radius (r/R) = 0.84.
- The magnitude of the blade force decreases with the increase of the distance between the shaft centerline and the point of load application.
- An average duration of the blade impact was 0.063 seconds.
- The greater the impact force magnitude, the shorter the duration of the impact.
- Small impulses are associated with large impact forces.
- Small ice blocks hitting the blade were the cause of the greatest magnitude blade forces recorded during the tests.

An influence of various parameters on the magnitude of blade force was investigated. The results are given below:

- RPM: An increase of RPM leads to an increase of the impact forces. This can be expressed by the equation:

  $$\text{Max Blade Force} = 80\,(\text{RPM} - 160)^{1/4}$$

  This equation reflects the test data only, and is not intended to represent the general trends. Low values of blade force at 160 rpm reflects a lack of data points at that speed.
  Varying the pitch settings does not alter this tendency.

- Propeller Pitch: Within 30% of the average pitch setting, no influence of the pitch setting on the magnitude of blade force was detected.
  Out-of-plane forces on the blade dropped drastically when the pitch decreased below 16°.
  Negative pitch settings produced very low impact forces.

- Ship Turning/Rudder Angle: When the ship is turning to port, higher frequency of interaction and higher impact forces are observed on the starboard propeller, than when the rudder is amidship or to starboard.

- Ship's Speed: There is no correlation between ship's speed and the magnitude of the maximum blade force. The hydrodynamic load on the blade can be expressed as:

  $$(BF)_{hydro} = 51.5 - 2.92 *(\text{ship's speed})$$

  Where the blade force is in kN, and ship's speed is in m/sec. The above formula is valid for full power only.

Analysis of shaft torque and thrust was then carried out using the data from 343 events. The main findings were as follows:

- Shaft Torque: The maximum shaft torque recorded was 305 kN * m which is twice the bollard torque. There is no correlation between the maximum torque and the maximum thrust. The maximum torques are associated with low thrust values. The maximum torque on one blade was five times the maximum continuous hydrodynamic torque on that blade at bollard. Shaft torque does not change with the change of rudder angle.

- Shaft Thrust: The mean value of shaft thrust in open water transits can be expressed as: - Thrust = 283 - 9.5 V, where thrust is in kN and V is in m/s. During the ice impact events, thrust fluctuations are large, in both ahead and astern directions. The maximum excursions of shaft thrust were 4.6 times the bollard thrust in ahead direction and 1.7 times in astern direction. These numbers require further verification due to the drift of the shaft thrust gauges. When operating in ice covered waters, the mean thrust level during the 6.81 second events rose to 2.2 times the hydrodynamic bollard thrust level.

Mean starboard shaft thrust increases with the rudder turned to port.

An investigation of the event durations revealed that:

- High impact forces are of short duration.
- The duration of ice/propeller interaction is equal to the time required to rotate the blade through the distance equal to the blade chord at the point of load application.
- Longer impact durations correspond to lower blade forces.

An analysis of the blade position at the instant of first contact with ice leads to the following conclusions:

- The presence of a skeg in the front of the nozzle has pronounced influence on the position at which ice contacts the propeller blade (a shadow is created where no ice is present).
- The maximum interaction with ice occurs at approximately 50° and 240° of blade position measuring counterclockwise from the 12 o'clock position. For the propulsion shafting strength calculations, the out-of-plane blade forces should be applied at approximately 80° and 270°. With such positions of force application the shaft excursions in the horizontal plane should be more pronounced than those in the vertical plane.

An analysis of the blade displacements due to the load showed that the ice impact induced vibrations of the blade, in water, lead to an increase of the average thrust. Water damping of the vibrations was found to be high (25% of the critical damping) and the added mass coefficient was found to be 4. The dynamic magnification of the blade response was found to be an important issue when scaling up of the results is involved. For the highest loads, which are of very short durations, the static load interpretation technique underestimates the forces.

The maximum blade bending moment recorded during the tests was 310 kN * m. This moment lead to the blade stresses exceeding the yield stress in compression.

A comparison of the data with the analytically derived formulations showed that the analytical model was too specific and the majority of its components were not verifiable. Only the large excursions of basic parameters, like RPM, pitch etc., lead to the significant changes of blade forces and bending moments. Therefore a "lumped-parameter" model was evolved, based on the data obtained, with the previously derived analytical model serving as a back-up, and explanatory tool for future use. The proposed model valid for the data collected only, is summarized below:

- Blade Force: Maximum blade force = -80 + 0.16 * shaft power (force in kN, power in kW). The direction of force application is perpendicular to the blade chord at r/R = 0.47. The radial point of load Application is at r/R = 0.7 while the Circumferential point of application is 1/2 way between the leading edge and the centre of the blade. The circumferential location of the blade force is subject to error due to the inability to directly measure the in-plane component of the force on the propeller blade. The duration of the blade force is equal to the time required to rotate the blade through the distance equal to the blade chord at the point of load application. This is the same result as from studying the shaft torque.

- Blade Bending Moment: The maximum blade bending moment (BBM) at the blade root (r/R = 0.37) is:

  $$(\mathrm{BBM})_{\mathrm{MAX}} = \text{Shaft kW}/11$$

  This is the total moment composed of both the hydrodynamic and ice induced loads.

- Shaft Torque: The maximum shaft torque is twice the bollard shaft torque, and its duration is 0.55 seconds.[1]

---

[1] Note: All of the durations given in this report are the response durations and not necessarily the durations of the applied load.

- Shaft Thrust: The maximum shaft thrust is 4.6 times the bollard thrust, and its duration is 0.05 seconds. The short duration of the peak thrust is due to the high stiffness of the shaft in the longitudinal direction, which leads to the high frequency vibratory response.

The comparison of the stresses calculated by using a tapered beam model and those measured during the calibration tests showed good agreement between the two. The ratio of compressive to tensile stresses at r/R = 0.6 is 1.48. This means that the neutral axis is closer to the blade pressure side and the higher stresses are generated at the suction side of the blade section.

The above summarized investigations and modelling work were carried out using "raw" data from the propeller and shafting gauges. The question of predicting the ice forces from the shaft response only, was addressed by building a three degrees of freedom lumped mass longitudinal and torsional model of the shafting system response to the thrust and torque impulses, respectively. Using torque and thrust gauge responses as calibrating functions, the input thrust and torque functions were derived using trial and error. The input functions were then compared to the propeller blade gauge signals to assure their compatibility. The main conclusions from this modelling were:

- Longitudinal and torsional models of the shafting system are suitable tools for the prediction of ice induced forces acting on the propeller blades.
- The models can be used to estimate the number of blades interacting with ice as well as the direction of the force acting on the blades.

The yoke-pin model was re-evaluated after the recalibration of the yoke-pin sliding block. The analysis of the sliding block, spindle torque and servo oil pressure sensors showed that:

- Due to friction in the pitch changing mechanisms, the maximum excursions of the blade spindle torque and sliding block loads cannot be measured accurately with the servo oil pressure.

- The friction in the blade carrier system limits the load on a sliding block to 90% of the value calculated under the no friction condition. This conclusion may be modified with the study of a more detailed yoke-pin model.

The analysis of the shaft-proximity probes data mounted at the stern-tube bearing was carried out. Only limited amount of the data was available due to probe failures. The main conclusions from the analysis are summarized below:

- There is a greater tendency for horizontal motion than vertical motion of the shaft in the aft stern-tube bearing.
- The motion is erratic and is forced at the blade passing frequency.
- The shaft contacts the bearing surface.
- The performance of the bearing is outside of the predictive capability of the standard (steady state) hydrodynamic bearing theory.

It was recognized from the onset of this project that the collection of a full season of data would be a valuable addition to the knowledge gained during the 5-day field program. Two types of recordings were gathered:

- Statistical data from torque and thrust signal.
- Sample recordings of torque, thrust and ship's speed.

When the long term shaft statistics were compared with those collected during the 5-day tests, the following relationships were established:

- Maximum shaft compression was 21% larger than the maximum recorded during the 5-day testing.
- Maximum shaft tension (while backing) was 127% larger.
- Maximum shaft torque was 10% larger.

An important conclusion derived from this comparison is that the 343 events are very representative of the whole season operations, except for the astern pitch maneuvers (tension in the shaft). These events are a very close approximation of the maximum ice loads MV Robert LeMeur encountered during the whole 1984 operating season.

Recommendations evolved from the work are listed below:

- General: Preliminary data analysis has indicated a significant departure from the previous understanding (based on the open propeller ice/propeller interaction) of ice interaction phenomena for a shrouded propeller. The issue is of such importance as to warrant more in-depth analysis in order to fully understand these findings. The analytical effort should be continued without a break. The timing is opportune because of the availability of the principal participants from the current study.

- Blade: Further study is necessary to quantify the influence of dynamic magnification of ice interaction with a blade. The influence of water on maximum blade loading should be analysed from the test data in order to allow scaling factors to be established for application to other vessels. Life cycle fatigue analysis of the blade and hub components should be undertaken in order to predict the onset of fatigue failure.

- Bearing: The test results require further study to determine: Scaling factor and zero offsets for the traces; misalignment data, and; acceleration forces created by radial displacement of the shaft. A MV Robert LeMeur bearing model should be developed capable of substantiating as far as possible, the findings of these field results. An approach to bearing design should be developed which incorporates the teachings of the bearing model. A suitable bearing should be designed, developed and tested to meet the needs of arctic shipping. Regulatory requirements for stern-tube bearings need to be drawn-up.

- Shaft System: Work is required on the development of more detailed models to incorporate combined ice/propeller interaction and machinery control parameters. These models should eliminate the approximations made with the existing models, and be made general enough for applications to other vessels. A statistical analysis should be preformed on the thrust and torque estimates from the above models. A series of propeller torque and thrust input functions during ice interaction should be generated for design purposes. A study should be done on the feasibility of creating models that predict propeller loads from shaft measurements only, for use in regulations and preventative maintenance programs, for propulsion systems operating in ice.

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B Catalogue of 343 Events
C Blade Stress-Strain Analysis
D Software Programs for Long Term Shaft Statistics Analysis
E Shaft Statistics Histograms and Tables
F Events from the Motion Recorder (DCS-302 Data)
G Propulsion Train Torsion and Longitudinal Model Development
H Shaft Torsional and Longitudinal Software Programs

SYMBOLS AND TERMS

c - location of force, measured from the leading edge, in meters
dm - incremental mass
exp(x) - exponent $x = e^{x}$
f - frequency, measured in Hz
f(m) - probability density of the ice block mass.
k - spring stiffness, in N/m
kW - shaft power, in kilowatts
ln(x) - logarithm base e
m - mass of the single degree of freedom system, measured in kg
p - pseudo-frequency, in Hz
r/R - relative radial location, defined as a ratio of the distance from a given point on the blade from the shaft centerline to the maximum radius of the blade.
s - distance of travel of the force, in meters
t - time, in seconds
w - blade chord width in meters
x - coordinate of the system, in meters
y - second derivative of the beam displacement in m^{-1}
y(o) - displacement of the beam under the load
$\dot{y}(o)$ - slope of the displacement line at the point of load application.

BF - blade force, acting perpendicular to blade section chord at r/R = 0.47, measured in kN
BM - bending moment, in kN.m
CB - centre bending signal
CPP - controllable pitch propeller
CQ - centre torque signal
E - elastic modulus of material, in pascals
F - tangential force acting on a blade in the plane of propeller disk, measured in kN
FFT - Fast Fourier Transform
I(x) - inertia of the blade section at location x measured in m^{4}.
L - Length of the blade, in meters
L.E. - leading edge of the propeller blade
LEB - leading edge bending signal
LEQ - leading edge torque signal
P(m) - probability of exceedance of mass m.
P.S. - pressure side of the blade (back-side)
Q - shaft torque, measured in kN.m
RPM - revolutions per minute
RPS - revolutions per second
S.S. - suction side of the blade
SM - section modulus of the blade, in m^{3}

T - shaft thrust, measured in kN
T_B - period of beat vibrations, in seconds
T.E. - trailing edge of the propeller blade
TEB - trailing edge bending signal
TEQ - trailing edge torque signal
V - ship's speed, measured in m/s
X_2, X_1 - successive amplitudes of freely vibrating beam, in meters
Y_{1A} Y_{1B} - the distance from the neutral axis to the surface of the blade.

$\propto$ - proportional to

ω - circular frequency, measured in s^{-1}
Θ - pitch angle at a given radius, in degrees
α - blade position angle measured counter clockwise from the 12 o'clock position looking forward; in degrees.
κ - ratio of the section inertia at a given location to that at the root.
μT - logarithmic decrement
ζ - damping ratio
λ - added mass coefficient
ξ - dynamic magnification factor
σ - stress in the blade, in pascals
φ - angle subscribing the arc of the blade segment, in degrees

1. INTRODUCTION

1.1 Previous Documentation

This report is the second of two reports which comprise the formal written documentation of this project. The first report was entitled "Measurement of Ice/Propeller Interaction Parameters - MV Robert LeMeur Engineering and Field Tests", and is referenced throughout this document as Milestone 1. An intermediate report, called Milestone 2, was required as a condition of the Contract to provide an update of progress following Milestone 1. This latter report has been superceded with the publication of the current document.

Care has been taken to ensure a continuity and completeness of reporting between Milestone 1 and this Final Report without requiring the reader to refer to Milestone 2. As a further assist in comprehension, some figures from Milestone 1 have been repeated here-in for ready reference. In other places, a short description of the appropriate Milestone 1 text is offered to set the stage for the subsequent writings.

1.2 Synopsis of the Milestone 1 Report

The purpose of the Milestone 1 Report was three-fold: It documented the type and choice of instrumentation used on the MV Robert LeMeur; It described in detail the field test program, and; It introduced a series of mathematical models developed specifically to describe the interrelationship between external load and induced stress in selected drive-train components. These three subjects are known as:

- The Preparatory Engineering Phase
- The Data Collection Phase
- The Model Phase

There was no attempt to analyse the data collected, nor to examine the utility of the models. Such review procedures were scheduled to be formally documented in the Final Report which is now presented. The Milestone 1 Report is an essential adjunct to the project and contains data which will not be re-introduced in this current volume.

The Preparatory Engineering Phase included a brief description of the MV Robert LeMeur and told of a previous attempt to collect scientific data using the same ship. From this experience, an expanded scope of measurements was undertaken and a quantum leap in the technology of data acquisition and storage was proposed. Details may be found in Sections 1. through 5. of the Milestone 1 Report. For ease of recollection, Figures 1.2-1 and 1.2-2 in this report have been transferred from Milestone 1.

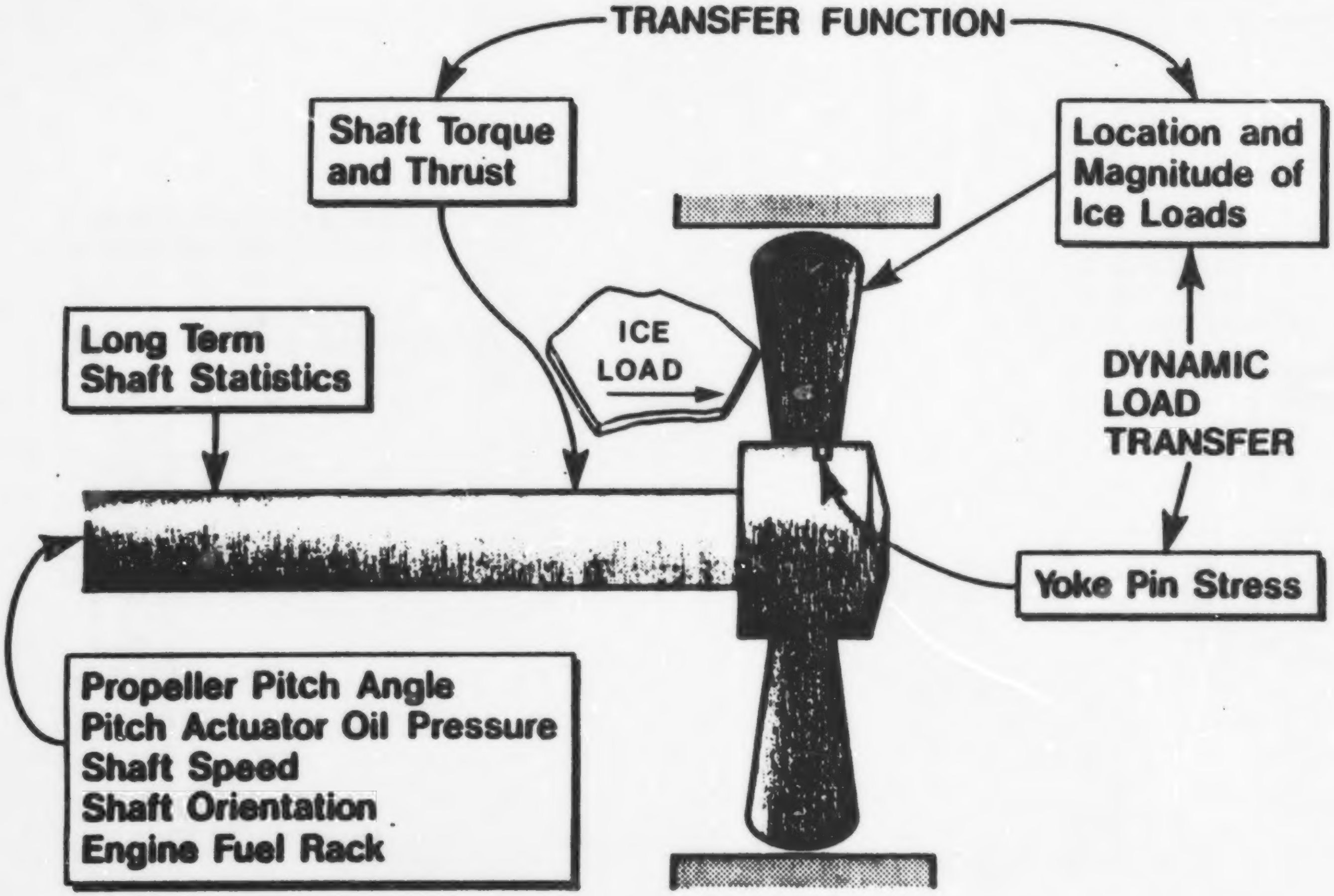
Figure 1.2-1 diagrammatically illustrates the location of the various transducers and defines the analytical model connection between the measurements. Figure 1.2-2 sketches the shafting layout. An appreciation of these figures will assist the reader in understanding some of the comments appearing later in this report.

Section 2. of the Milestone 1 Report deals with the design and installation of strain-gauges: On one propeller blade; On the related yoke-pin sliding block in the Controllable Pitch Propeller (CPP) mechanism, and; On the intermediate shaft. In addition, the location of inductive proximity probes, in way of the aft Stern-Tube bearing, is described. Other ship-borne transducers are also itemised, together with the associated signal-conditioning equipment.

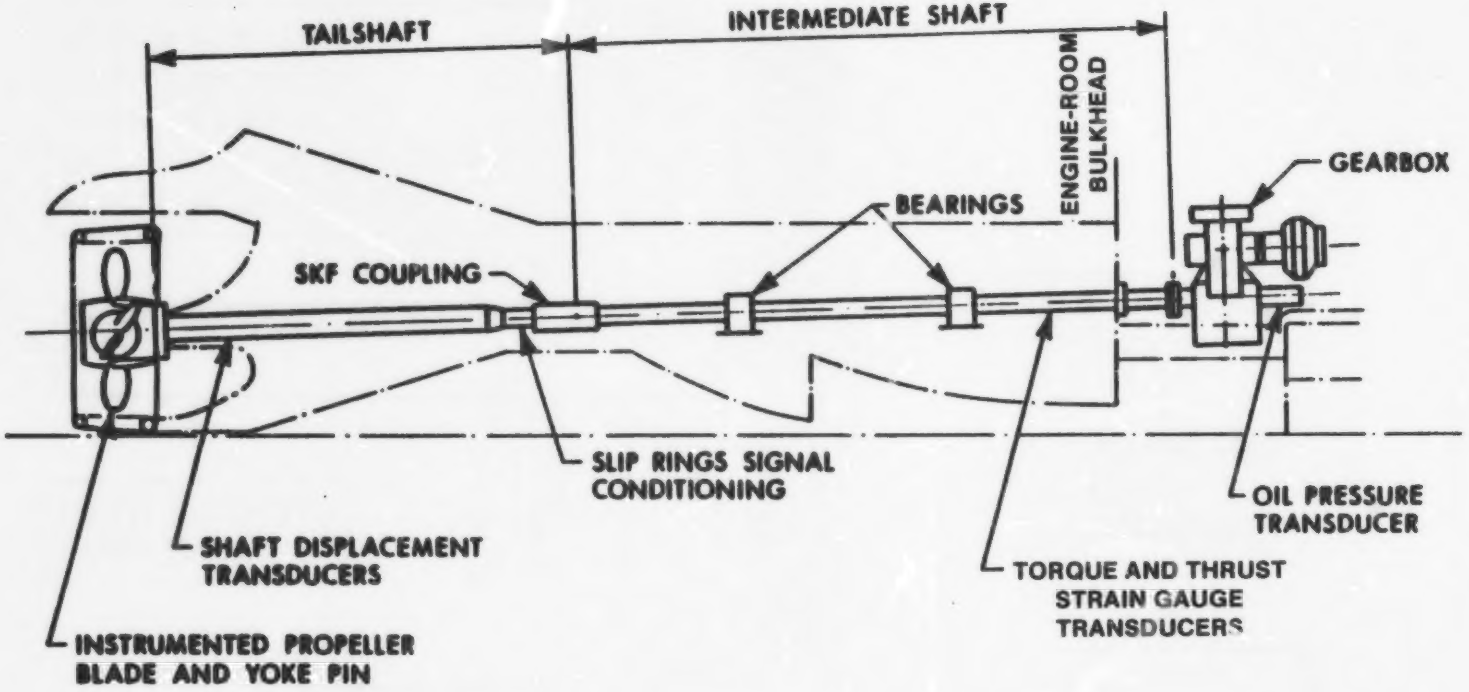
Section 3. of the Milestone 1 Report concentrates on the complexities of interpreting data from the six strain-gauge bridges encapsulated within the instrumented propeller blade. Both static and dynamic calibration procedures are described in detail. Of particular importance, is the introduction of an algorithm called the Influence Coefficient Method for correlating external loading conditions with the strain-gauge readings.

Section 4. of the Milestone 1 Report deals in a similar fashion with the sliding block instrumentation and calibration. In Section 5., an itemised list of the transducer signals, and associated calculated values of forces, moments, torques, etc., is provided. An updated version of this list appears later in this report as table 4.1-1. Also described is the software package called "ANALYZE" which was written to handle the collected data and perform the desired mathematical manipulations.

The Data Collection Phase of the project is succinctly covered in Section 6. of the Milestone 1 Report. The essential ingredient for the present purpose is to record that a nominal Five-Day test period was conducted between June 30 and July 04, 1984. During that time, 343 recordings of "events" were made. Data from these events comprise the major subject matter for the analysis presented herein.


TRANSFER FUNCTION
Shaft Torque and Thrust
Location and Magnitude of Ice Loads
Long Term Shaft Statistics
ICE LOAD
DYNAMIC LOAD TRANSFER
Yoke Pin Stress
Propeller Pitch Angle
Pitch Actuator Oil Pressure
Shaft Speed
Shaft Orientation
Engine Fuel Rack

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: PROPULSION LOADS MEASUREMENT SCHEME
		FIGURE No. 1.2-1


TAILSHAFT
INTERMEDIATE SHAFT
ENGINE-ROOM BULKHEAD
GEARBOX
BEARINGS
SKF COUPLING
SLIP RINGS SIGNAL CONDITIONING
OIL PRESSURE TRANSDUCER
SHAFT DISPLACEMENT TRANSDUCERS
TORQUE AND THRUST STRAIN GAUGE TRANSDUCERS
INSTRUMENTED PROPELLER BLADE AND YOKE PIN

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MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE: LOCATION OF TRANSDUCERS
ON STARBOARD SHAFT

FIGURE No. 1.2-2

Also recorded during the Data Collection Phase was ice condition data which provided another facet to the understanding of icebreaker propulsion-train loads. A general review of the local ice conditions during the Five-Day test period is presented.

Section 6. also reports on the successes and failures of the various transducers and signal conditioning equipment. However, it does not describe an extended period of data collection which followed the Five-Day test. Full details are therefore included in this Final Report together with an extensive evaluation of the data.

The third purpose of the Milestone 1 Report, i.e., the derivation of the mathematical models, is handled in Sections 7. through 10. These sections described the following models:

- The Ice Interaction Model
- The Blade Model
- The Yoke Pin Model
- The Torsional and Longitudinal Shaft Models

It was the intention of the research workers to produce these models as a preliminary feature to the field trials in order to provide an insight into the validity of the incoming data. They were therefore derived from simple theories, and an objective of this Final Report is to compare these models with the test data, in order to determine how effectively they describe and predict actual happenings when an icebreaker is at work.

1.3 Overview of Post-Milestone 1 Activity

With the conclusion of the field data-gathering stage, and the submission of the Milestone 1 report, the project entered a new phase of activity. It also meant a change in personnel to some extent, as the instrumentation and field workers gave way to the computer program writers and the analysts.

Due to the success of the field trials, a vast quantity of data was produced; data which contained many insights into the operation of a ship's propulsion system in ice-infested water. The information was, of course, particular to a mechanical drive with a Controllable Pitch Propeller operating within a nozzle, but as this project was the first elaborate attempt at measuring the effects of ice on such a propulsion train, every finding constituted an advance in the level of knowledge.

The quantity of data was of such magnitude that research analysts could pore over the results for years into the future. The problem was to select the specific areas of particular interest, and to determine to what depth of study each subject was entitled. This decision process was largely a matter of continual re-appraisal, judged against the background of a ticking clock signifying the consumption of finite time and human resources. As the process of analysis continues and different avenues of investigation are pursued, more findings will emerge. It is believed, however, that most of the major discoveries were unearthed in the present study and these are presented in the following pages.

No matter which scientific dilemmas faced the researchers, certain housekeeping chores had to be carried out. Firstly, it was necessary to ensure that all the data was stored, catalogued and protected. Back-up copies of the data had to be made in case of catastrophic loss of the originals.

A second task was to debug the information, by searching for inconsistencies and obviously erroneous signals. But this task is apparently never-ending, in so far as when the data is subjected to closer and closer scrutiny, various anomalies begin to appear. These anomalies might be significant discoveries, or just errant transducer readings. In some instances, uncertainties in scaling factors or zero offsets were encountered, and, where possible, corrections have been made. It is estimated that the records are now 90 to 95% debugged.

Throughout these tasks, the policy adopted was to cause the suspect information to be rejected or corrected by the software program. It was decided not to obliterate the offending material from the original data disk. This precaution was exercised in order to permit critical review in the future, should a new line of thinking emerge.

A third task was to write the computer software packages in a "user friendly" fashion, because it was recognised that the present team assembled by Canmar, could not be expected to endure. Neither would it be necessarily beneficial for the same research workers to have the only access to the data. The software programs have therefore been written with a view to facilitating the entry of independent researchers into the data bank.

1.4 Format of Final Report

After this introductory chapter, the next section spells out the objectives of the report, pointing to specific areas of scientific interest. The objectives comprise a menu to whet the appetite of the reader.

Chapter 3, provides a catalogue of background information, including the ship's particulars with descriptions of the individual propulsion train componentry, and a record of the ice conditions encountered during the Five-Day test period.

The body of the report is found in Chapters 4 and 5, which contain the analyses of the data and an assessment of the various models introduced in Milestone 1. Where appropriate, the subsections have been written as individualised statements, replete with their own Introductions and Conclusions. This format was adopted to permit specialised workers to dwell on their specialities without having to sift through the whole gamut of topics.

The final chapters follow the traditional course with Conclusions and Recommendations. Eight appendices have been compiled and are presented in a separate volume. The purpose of the appendices is mainly to provide an audit trail through the masses of data collected during the project. This information may be conveniently ignored if an understanding of the findings of this work is all that is desired, but it is essential if further analysis or checking of the conclusions is undertaken.

2. OBJECTIVES

The objectives of the post data-collection phase of the project are listed below:

- To prepare, preserve, and protect the test data for later use.
- To prepare software packages in "user friendly" format for use by other research workers.
- To de-bug the data.
- To conduct a preliminary analysis of the data.
- To use the analysis to report on the following topics:

  i. Ice/Propeller Interaction: To determine from the test data, the types and magnitudes of ice/propeller encounters, including hydrodynamic effects. To compare the frequency and severity of ice interactions with ship operating variables. To evaluate the Ice Interaction Models proposed in Milestone 1 and offer amended versions.

  ii. Propeller Blade: To observe the response of the instrumented blade to its interaction with ice, especially with reference to the effect of dynamic magnification. To evaluate the accuracy of the Simple Beam Blade Model proposed in Milestone 1.

  iii. Yoke Pin: To combine the findings of the static calibrations, the field test results, and the Yoke Pin Model to determine the influence of friction at the blade foot in attenuating load impulses from the blade to the yoke pin.

  iv. Shaft: To measure the shaft torque and thrust responses to ice/propeller interactions and compare with the Simple Shaft Models proposed in Milestone 1. To evaluate the possibility of substituting shaft strain-gauges for blade strain-gauges for interpreting ice loading conditions on a propulsion system over an extended period of time. To collect data of shaft torque and thrust fluctuations over an operating season and determine its statistical importance.

v. Bearing: To observe the motion of the tail shaft within the stern-tube bearing and explain its significance for bearing design.

vi. Long Term Shaft Statistics: To determine how representative the 343 tests were of a complete operating season. To determine shaft torque and the cycles during the whole operating season for potential future use in determining propulsion train fatique. To record sample shaft torque and thrust signals during the largest shaft torque event of the operating season.

3. BACKGROUND INFORMATION

3.1 Ship Data

The basic parameters of the MV Robert LeMeur are listed in Table 3.1-1. The ship is designated as a CASPPR Class 3 ice breaking supply vessel, and classed by Lloyds Register as 100A1. It was built by Burrard Yarrows Shipyard in Vancouver, British Columbia, in 1982 for Dome Petroleum Ltd. Its duties have been to support the Canmar drilling fleet in the Beaufort Sea.

The ship has two engines, each of approximately 3,500 kW. Each engine powers a controllable pitch propeller (CPP) through a single ratio step down gear box. The propellers are shrouded by custom designed nozzles.

The following figures provide details of selected propulsion train components:

Figure No.	Description
1.2-2	Shafting Arrangement
3.1-1	Propeller Profile
3.1-2	Sterntube Bearing Details
3.1-3	MV Robert LeMeur General Arrangement

3.2 Propulsion Train Protection

Each of the two propulsion trains, consisting of diesel engine, fly wheel, clutch, gearbox controllable pitch propeller, is controlled and protected as an integrated system by a separate microprocessor-based control and monitoring unit.

The microprocessor unit interfaces with the individual control systems of the elements of the propulsion train, i.e. the oil distribution box, the engine governors and the clutch control, thereby preserving the primary means of protection for each

Ship:

Length Overall	82.8 m
Breadth Moulded	18.0 m
Icebreaking Draft	5.5 m
Deadweight	2690.4 tonnes
Engine Power at M.C.R.	3530 kW

BEAM/Propeller Dia Ratio = 6

Propulsion:

		NUMBER
Engine	M.A.K. 12M45EV	2
Clutch	L&S PNEUMAFLEX KA320MD	2
Gearbox	L&S GCE8505	2

Propellers

LIPS	CPP
Hub Type	4C115W
Number of Blades	4
Propeller Speed	209 RPM
Hub to Prop. Dia. Ratio	0.367
Propeller Diameter	3.0 m

Pitch Mechanism

Design pitch angle at 0.7 r/R	26.48°
Maximum astern pitch angle	19.66°
Bollard Pitch angle	26.12°

BLADE:

Mass of Blade w/o Foot	452 kg (C.O.G. - 0.947 m)
Mass of Blade w/ Foot	615 kg (C.O.G. - 0.819 m)
Material	Cunial Bronze
Ultimate	647 MPa
Yield	260 MPa
Elongation	20%
Blade width	1.0 m
Thickness of blade tip	.025 m
Young's Modulus E	1.3×10^{11}Pa
Poisson Ratio	0.3
	48 800 MPa
U.T.S.	647 MPa
Yield	260 MPa

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: BASIC PARAMETERS
M.V. ROBERT LEMEUR DATA

TABLE 3.1 - 1

Nozzle:

Nozzle Inside Diameter	3.03 m
Nozzle Length	1.4 m
Length to Prop. Dia. Ratio	0.4667

List of natural frequencies of the propulsion train components.

Shaft	3.48 Hz	
Blade	13.9 Hz	
Blade Bending (Fixed-Free Condition)	40 Hz	In Water Fundamental
	90 Hz	In Air Fundamental
	120 Hz	In Air Second Mode
Blade Torsion	138 Hz	In Air
Shaft Longitudinal (Including propeller, added mass and flywheel)	25.5 Hz	fundamental
	76.1 Hz	second
	106.0 Hz	third
Shaft Torque	3.58 Hz	fundamental
	13.89 Hz	second
	27.12 Hz	third
	42.27 Hz	fourth
Ship Hull Vibrations	2.24 Hz	

Construction Pitch Angle

r/R (-)	CONST (DEG)
0.37	39.5
0.40	37.6
0.5	32.8
0.6	29.3
0.7	26.5
0.8	24.2
0.85	23.3
0.90	22.4
0.95	21.5
1.00	20.8

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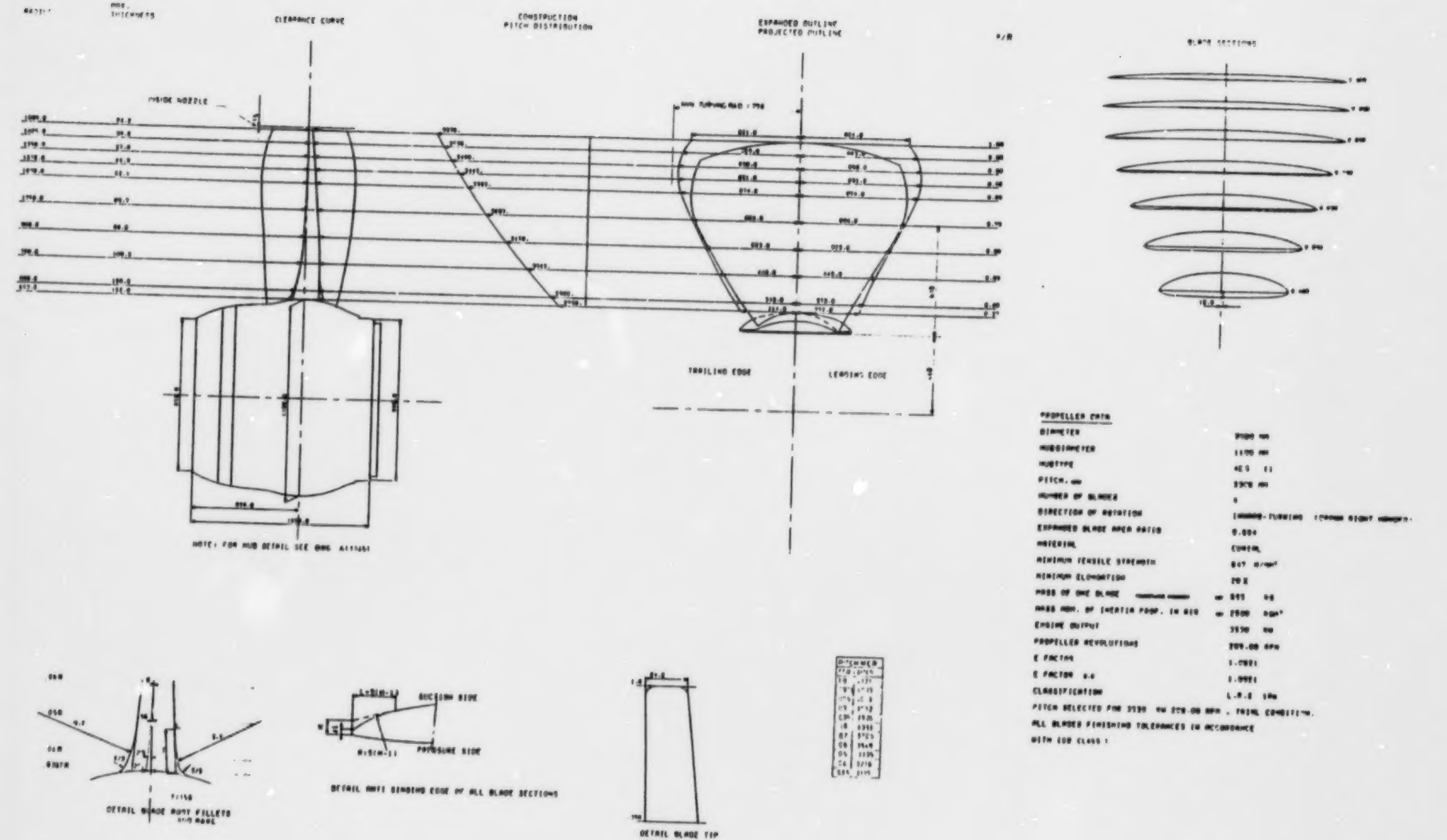
PROPELLER INTERACTION
PARAMETERS

TITLE:
BASIC PARAMETERS
M.V. ROBERT LEMEUR DATA

TABLE 3.1 - 1 CONT'D.


RADII
MAX. THICKNESS
CLEARANCE CURVE
CONSTRUCTION PITCH DISTRIBUTION
EXPANDED OUTLINE
PROJECTED OUTLINE
R/R
BLADE SECTIONS
INSIDE NOZZLE
TRAILING EDGE
LEADING EDGE
NOTE: FOR HUB DETAIL SEE DWG.
PROPELLER DATA
DIAMETER
HUBDIAMETER
HUBTYPE
PITCH
NUMBER OF BLADES
DIRECTION OF ROTATION
EXPANDED BLADE AREA RATIO
MATERIAL
MINIMUM TENSILE STRENGTH
MINIMUM ELONGATION
MASS OF ONE BLADE
MASS MOM. OF INERTIA PROP. IN AIR
ENGINE OUTPUT
PROPELLER REVOLUTIONS
E FACTOR
E FACTOR
CLASSIFICATION
PITCH SELECTED FOR
ALL BLADES FINISHING TOLERANCES IN ACCORDANCE WITH ISO CLASS I
SUCTION SIDE
PRESSURE SIDE
DETAIL ANTI SINGING EDGE OF ALL BLADE SECTIONS
DETAIL BLADE ROOT FILLETS
DETAIL BLADE TIP
SCALE 1:1.0

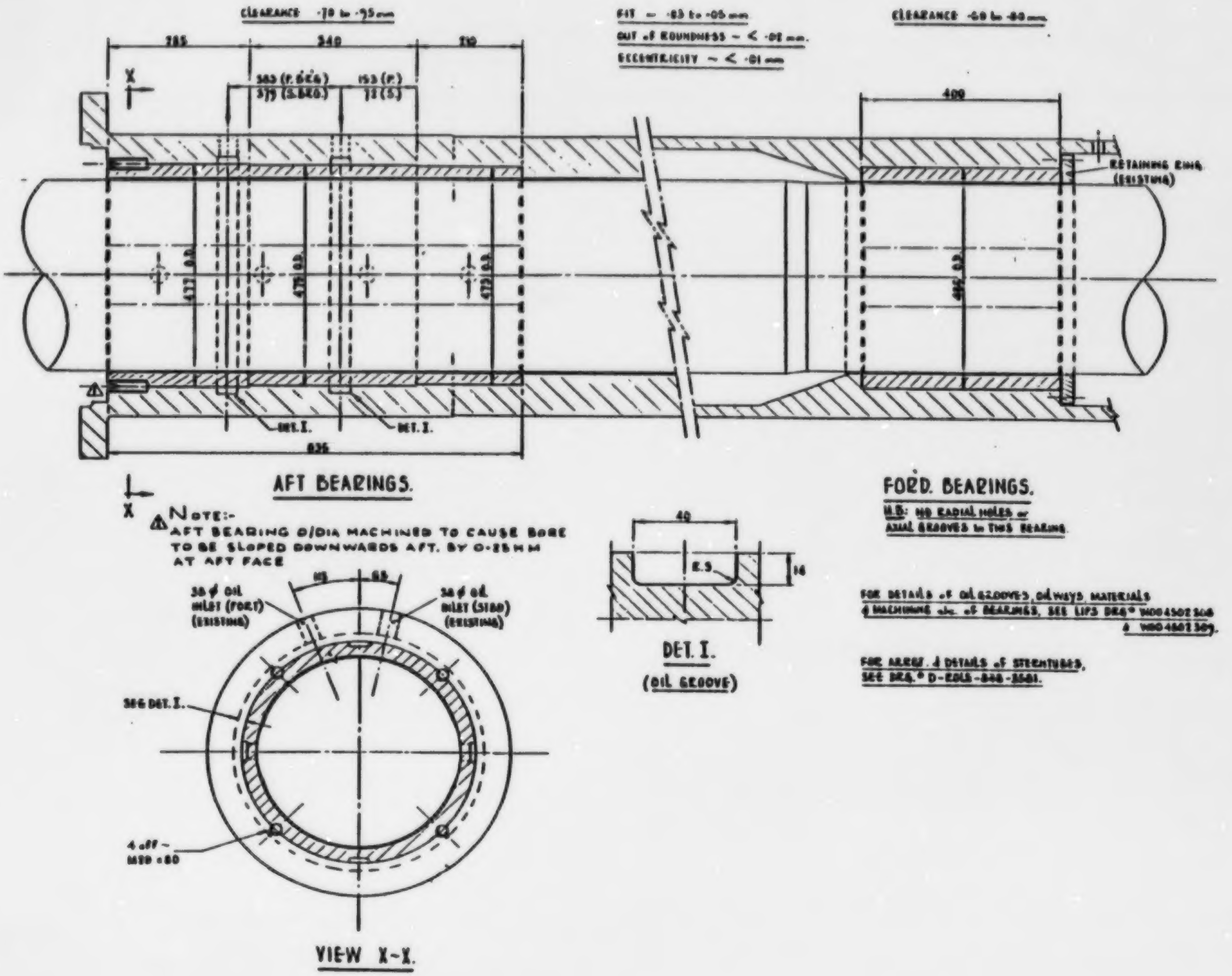
CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:

PROPELLER PROFILE

FIGURE No. 3.1 - 1

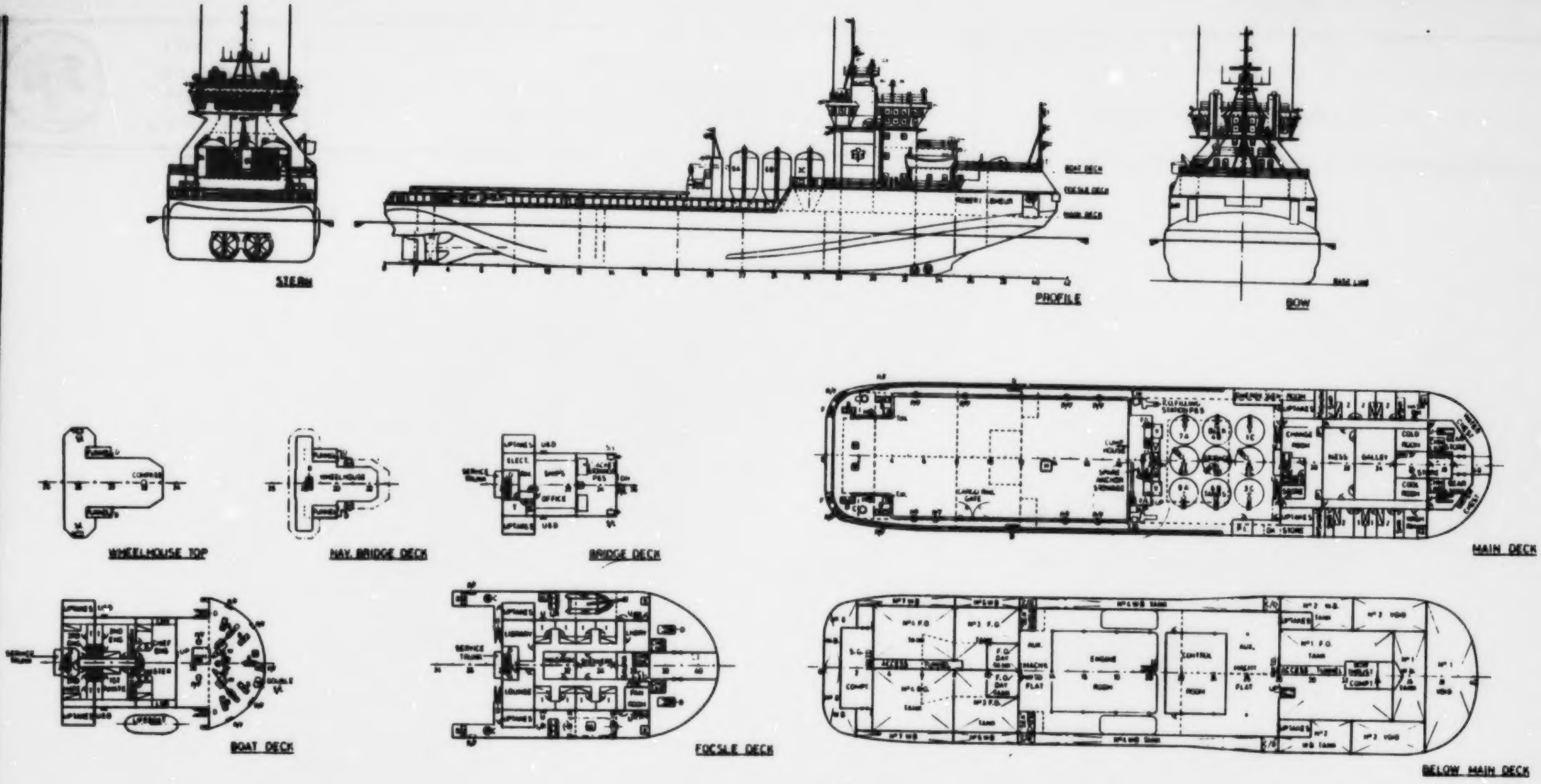

CLEARANCE ·70 to ·95 mm
285
340
210
X
383 (P. BRG.)
379 (S. BRG.)
153 (P.)
72 (S.)
477 O.D.
475 O.D.
472 O.D.
DET. I.
DET. I.
835
AFT BEARINGS.
X
NOTE:-
AFT BEARING O/DIA MACHINED TO CAUSE BORE TO BE SLOPED DOWNWARDS AFT. BY 0·25 MM AT AFT FACE
FIT ~ ·03 to ·05 mm
OUT of ROUNDNESS ~ < ·02 mm.
ECCENTRICITY ~ < ·01 mm
CLEARANCE ·60 to ·80 mm
400
495 O.D.
RETAINING RING (EXISTING)
FORD. BEARINGS.
N.B: NO RADIAL HOLES or AXIAL GROOVES in THIS BEARING.
FOR DETAILS of OIL GROOVES, OILWAYS, MATERIALS & MACHINING etc. of BEARINGS, SEE LIPS DRG.° W004502308 & W004802309.
FOR ARRGT. & DETAILS of STERNTUBES, SEE DRG.° D-EOLS-848-3501.
40
8.5
14
DET. I.
(OIL GROOVE)
65
65
38 ⌀ OIL INLET (PORT) (EXISTING)
38 ⌀ OIL INLET (STBD) (EXISTING)
SEE DET. I.
4 off ~ M20 × 80
VIEW X-X.

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: STERN TUBE BEARING DETAILS

FIGURE No. 3.1 - 2


STERN
PROFILE
BOW
BOAT DECK
FOCSLE DECK
MAIN DECK
BASE LINE
WHEELHOUSE TOP
NAV. BRIDGE DECK
BRIDGE DECK
MAIN DECK
BOAT DECK
FOCSLE DECK
BELOW MAIN DECK
ENGINE ROOM
CONTROL ROOM
MESS
GALLEY
OFFICE
WHEELHOUSE
SERVICE TRUNK

GENERAL PARTICULARS

LENGTH OVERALL	87·800 METRES
LENGTH DISPLACEMENT	78·000 M
LENGTH ICEBREAKING W.L.	79·125 M
BREADTH EXTREME (OVER REAMERS)	19·034 M
BREADTH MOULDED	18·000 M
DEPTH MLD. TO FOCSLE DECK	10·500 M
DEPTH MLD. TO MAIN DECK	7·500 M
SUMMER DRAFT MLD.	5·668 M
ICEBREAKING DRAFT	5·500 M
FRAME SPACING	2·000 M
DEADWEIGHT (MAXIMUM)	2690·4 TONNES
PORT OF REGISTRY	EDMONTON, ALBERTA.
REGISTERED TONNAGE	1501·49
OFFICIAL NUMBER	801810

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
M.V. ROBERT LEMEUR GENERAL ARRANGEMENT

FIGURE No. 3.1-3

element. At the same time it looks at the system as a whole and provides additional safeguards, i.e. by reducing fuel when a clutch fault occurs or by giving the auto centering command to a rudder when a pitch reversal is made.

The clutch disconnects when the torque in the system exceeds 200% of the maximum continuous torque level.

Three control modes appropriate to the prevailing ice conditions are available to the navigating officer (Reference 3.2-1).

The combinator mode is intended for use in open water condition when the ship is proceeding at steady power and speed. Programmed into the microprocessor software, is a curve matching propeller pitch to engine speed for any given telegraph setting. The curve is chosen to optimize fuel efficiency.

Constant speed mode is for use in ice conditions when ramming is infrequent or in open water when frequent maneuvering is anticipated. In this mode, engine speed is maintained constant by the governors and the telegraph level becomes a pitch control.

Icebreaking mode is intended for use when there is a high ram cycle frequency. With this arrangement, which was specially developed by Canmar, the engine delivers constant power and the pitch changes automatically to suit the ship's speed and the prevailing ice conditions. One distinct advantage of this system is the impossibility of overloading the engine. Where a conventional governor control system would increase fuel under excess torque conditions and thereby run the risk of engine damage, this mode control attacks the cause instead of the symptoms and reduces pitch, thereby reducing torque.

3.3 Ice Block Size Distribution

The ice block size distribution for the field trials of the MV Robert LeMeur propeller in June/July 1984 was determined from the analysis of photographs taken during the field programs. The ice conditions during the program are detailed in Milestone 1.

A 35 mm camera was mounted on one of two fixed platforms, (one at the bow and one at the stern). Photographs were taken at arbitrarily selected times throughout the trials. Once developed, standard photogrammetric methods were used to determine the scale of the picture. Transect lines were then drawn on the photographs across the ship's channel and ice block sizes were measured along them. The size of the blocks was then converted into mass. The frequency of ice block size distribution is documented in Table 3.3-1, (Reference 3.3-1).

As in the ice block size distribution for 1983 (Spencer 1984, Reference 3.3-2) the probability of exceedance function P (m), is defined as:

$$P\ (m) = \int_{m}^{\infty} F(m)dm / \int_{-\infty}^{+\infty} F(m)\ dm$$

where F (m) is the frequency of occurrence of a given block of mass m.

The data given in lines 1 to 6 were fitted to a log normal distribution function, shown in Figure 3.3-1, giving

$$F\ (m) \propto \exp(-0.0853\ (\ln\ (m) - 5.25)^2)$$

This curve is similar to that given by Wind 1983, Reference 3.3-1 where

$$F\ (m) \propto \exp(-.207\ (\ln\ (m) - 4.6)^2)$$

The data obtained during the 1983 MV Robert LeMeur field trials fit the curve

$$F\ (m) \propto \exp(-0.370\ (\ln\ (m) - 2.4)^2$$

Another author, Tuovinen (1979 - Reference 3.3.-3), found that the block sizes of 3 different channels in the Baltic Sea also fit a log normal distribution function well.

The 1984 curve shows an exceedance probability of 0.5 for a block of 0.125 m^3 (ln (mass) = 5), equivalent to approximately 11 kg. The largest block size recorded was 18.8 m^3 (ln (mass) = 10) with an exceedance probability of 0.048. The total sample included 115 blocks.

These values differ from the values determined from the 1983 data in that there is a higher probability of encountering large ice blocks in the 1984 sample than the 1983 sample. This may be due to several factors. The ice channel that was broken in the 1983 tests had been previously broken, therefore the ice entering the nozzle would have a higher proportion of small pieces producing an ice block distribution with a high probability of

ln Mass	Equivalent Mass (kg)	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Sum of Lines
0.5	0- 1.81		2		5			7
1.0	1.81- 2.99							
1.5	2.99- 4.93		2	1	2			5
2.0	etc - 8.12	4				2	1	7
2.5	" - 13.39			2	1			3
3.0	" - 22.07							
3.5	" - 36.39	3	1	1	1	2		8
4.0	" - 60.00	1	1	1	2			5
4.5	" - 98.93	4	2	1	2	4	2	15
5.0	" - 163.11	1	1	3		2		7
5.5	" - 286.92	2	1	2		1	1	7
6.0	" - 443.37		2	2				4
6.5	" - 730.99					3	3	6
7.0	" - 1205.20	2	2		2	1	2	9
7.5	" - 1987.04	4	2	3	4	2	3	18
8.0	" - 3276.07			1	1	2	2	6
8.5	" - 5401.33		2	1	1	1		5
9.0	" - 8905.29						1	1
9.5	" -14682.34							
10.0	" -24207.09					1	1	2
Cumulative frequency		21	18	18	21	21	16	115

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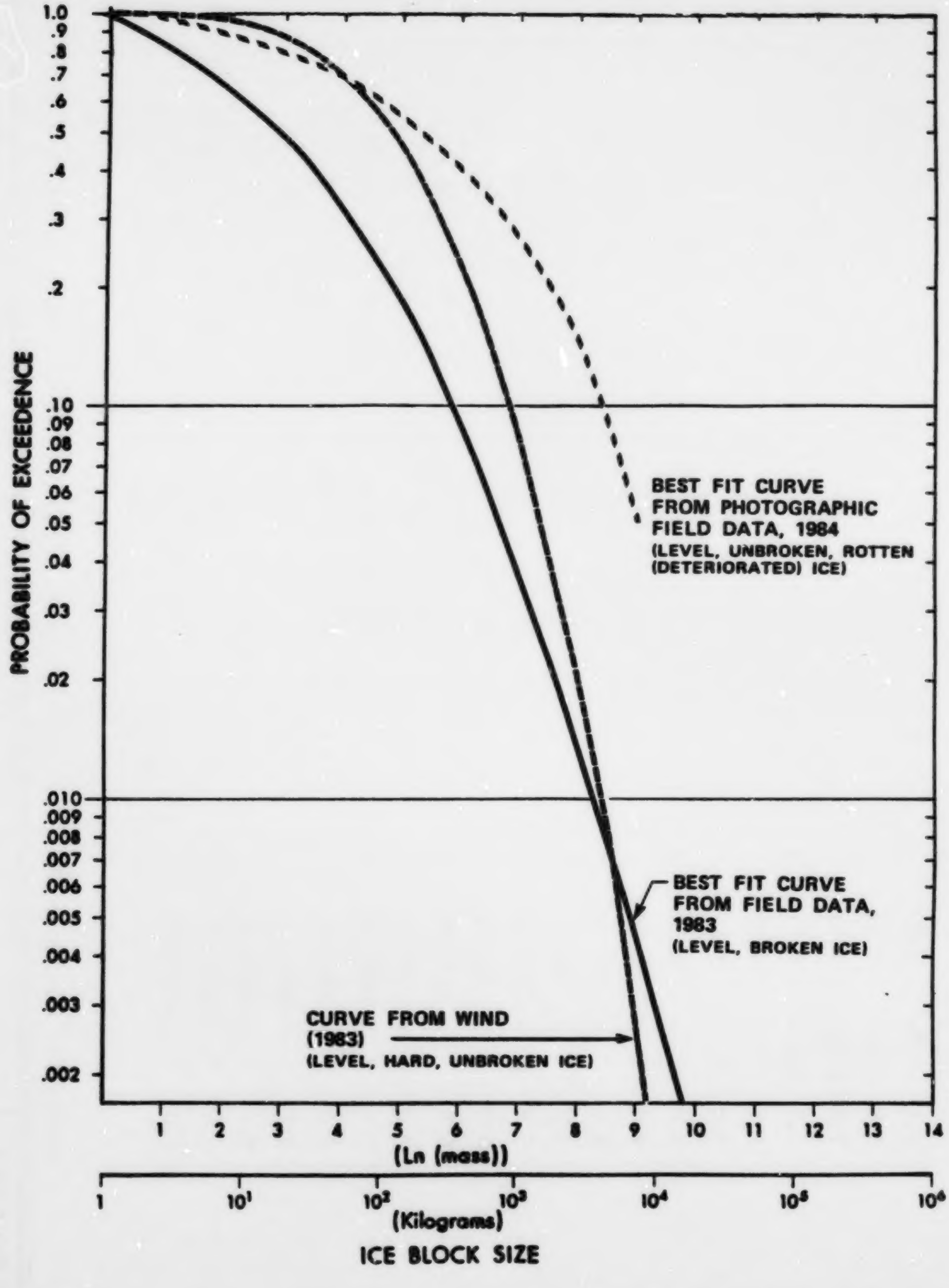
TITLE: FREQUENCY OF ICE BLOCK SIZES OBTAINED FROM LINES OF OBSERVATION, JUNE/JULY 1984

TABLE 3.3-1



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TITLE: EXCEEDENCE PROBABILITY OF BLOCK SIZE DISTRIBUTION MEASURED DURING JUNE TESTS, 1983 AND THE BEST FIT CURVE. ALSO INCLUDED IS THE THEORETICAL CURVE BY WIND (1983).

FIGURE No. 3.3-1

small blocks. The ice encountered in the 1984 tests was unbroken and, as a result could be expected to produce a population of ice blocks with a larger mean size.

The ice block size data for the 1984 tests was, of necessity, taken from photographs. Therefore, due to the effective distance and angle from which the observations were made, the sample might have included an unrealistically low concentration of small ice pieces.

In 1983 the ice block measurements were made on a one-to-one scale from a point perpendicular to the channel surface. In 1984 the scale of the photographs was 1:76 and they were taken from an oblique angle, resulting in less definition and lower resolution making it difficult to see the small pieces.

In conclusion, the three curves shown in Figure 3.3-1 follow log normal distributions and are consistent when the differences in data base parameters such as ice thickness and channel conditions are taken into account.

4. ANALYSIS OF THE FIVE-DAY TEST DATA

4.1 Data Storage and Computer Software Programs

On return from the five-day field tests in early July, 1984, one of the first tasks was to make a duplicate copy of the 343 data disks recorded during the test program. Rather than simply make another set of floppy disks, the duplicate copy was made on nine-track I.B.M. compatible tape. A program was specifically written for this conversion. The change had the advantage that the data could be read by an IBM mainframe. Furthermore, having approximately 60 events stored on one tape would facilitate the unattended "batch mode" analysis of data.

A second set of nine-track IBM. compatible tapes was produced in November, 1984 and stored in the Dome archives to protect against loss of data in the event of a local fire or flood. Copies of the software matter for the project were also made and stored in the Dome archives.

Two software programs were written for the analysis of the 343 events. They are called "ANALYZE4_1" and "STATALYZE8".

The "ANALYZE4_1" program was first described in the Milestone 1 Report. It is used to manipulate the raw data from:

- 20 Dynamic Blade Calibrations
- 343 test disks
- 6 nine-track back-up data tapes

The following blade quantities can be calculated from the raw data:

- Out-of-plane bending moment[2]
- Out-of-plane blade force
- Spindle torque
- Radial location of the load on the propeller blade
- Circumferential location of the load on the propeller blade

---

[2] The "plane" is the vertical plane passing through the blade section chord at relative radius (r/R) = 0.47. The "Out-of-plane" is the vertical plane perpendicular to that plane.

A copy of the computer program listing for "ANALYZE4_1" is given in Appendix A. There have been a number of changes to the "ANALYZE4_1" program since it was described in Milestone 1. An updated listing of the channels of data available is provided in Table 4.1-1. The changes include "Help", "Batchmode" and "Statistics" soft-keys. The "Help" soft-keys assist the user in understanding the program, with information and comments about each channel of data. The instructions built into the program are arranged to match the function soft-key chosen. In this way, help can be obtained on any specific topic.

The "Batchmode" soft-key is used to run the program in an unattended mode. A specific set of calculations, complete with output to paper and/or disk is performed on each test, the next set of test data is then read, and the functions repeated. The data can be read from the Nine-Track tapes, which allow the same calculations to be performed on approximately 59 sets of test data in one batch run. This mode was used to perform statistical analysis on all of the tests to produce a single disk containing "min", "max" and "mean" values for each channel. The calculations also identified the readings for the single largest shaft torque, shaft thrust and blade force occurrence for each test. This particular batch run took approximately 9 hours to complete each nine track tape.

"ANALYZE4_1" is able to recognize the presence of torque, thrust and blade force occurrences according to criteria encoded into the program. The types of data stored for shaft torque and thrust events are:

- The start time of the occurrence
- The time of the occurrence peak
- The end time of the occurrence
- The corresponding shaft torques and shaft thrusts for each of these times

Other statistics besides "min", "max" and "mean" are stored for the blade force, i.e., the other blade force statistics stored for each occurrence are:

- Radial location on the blade of the peak blade force
- Circumferential location on the blade of the peak blade force
- The impact impulse in kN * sec, for the peak blade force
- The direction of the peak blade force

CHANNEL LISTINGS FOR ACTUAL TEST DATA

#	CHANNEL DESCRIPTIONS	UNITS	COMMENTS
	ACQUIRED CHANNELS		
1	CENTRE BENDING	MPa	POS SIG FOR TIP BENDING FORWARD
2	TRAILING EDGE TORQUE	MPa	POS SIG FOR TRAIL. EDGE BENDING FWD
3	LEADING EDGE BENDING	MPa	POS SIG FOR TIP BENDING FORWARD
4	CENTRE TORQUE	MPa	POS SIG FOR TRAIL. EDGE BENDING FWD
5	TRAILING EDGE BENDING	MPa	POS SIG FOR TIP BENDING FORWARD
6	LEADING EDGE TORQUE	MPa	POS SIG FOR TRAIL. EDGE BENDING FWD
7	SLIDING BLOCK FORCE	kN	POS SIG FOR TRAIL. EDGE BENDING FWD
8	SHAFT THRUST	kN	POS SIG IS SHAFT IN TENSION
9	SHAFT TORQUE	kN.m	POS SIG IS ENGINE DRIVING SHAFT
10	SERVO OIL PRESSURE	bar	POS CHANGE INCREASES PITCH ANGLE
11	AFT TOPE PROBE	mm	POS CHANGE, INCREASING SEPARATION
12	FWD PORT PROBE	mm	POS CHANGE, INCREASING SEPARATION
13	FWD PORT PROBE	mm	POS CHANGE, INCREASING SEPARATION
14	FWD STRB PROBE	mm	POS CHANGE, INCREASING SEPARATION
15	SHAFT RATE PULSE	volt	TEN O'CLOCK LOOKING FORWARD, 1/REV
16	PROPELLER PITCH	deg	POS SIGNAL, AHEAD PITCH
17	SHIP SPEED	m/s	ABSOLUTE VALUE OF VELOCITY
18	RUDDER ANGLE	deg	POS SIG IS STBD.
	CALCULATED QUANTITIES		
19	BENDING MOMENT	kN.m	POS SIG FOR TIP BENDING FORWARD
20	SPINDLE TORQUE	kN.m	POS SIG FOR TRAIL. EDGE BENDING FWD.
21	FORCE	kN	POS SIG FOR TIP BENDING FORWARD
22	RADIAL LOCATION	m	DISTANCE FROM BLADE ROOT, (0.37 RR)
23	CIRCUMFERENTIAL LOCATION	m	DISTANCE FROM BLADE C.L., LE IS POS
24	BENDING MOMENT (FILTERED)	KN.m	POS SIG FOR TIP FORWARD
25	SPINDLE TORQUE (FILTERED)	KN.m	POS SIG FOR TRAIL. EDGE BENDING FWD
26	FORCE (FILTERED)	kN	POS SIG FOR TIP BENDING FORWARD
27	RADIAL LOCATION (FILTERED)	m	DISTANCE FROM BLADE ROOT, (0.37 RR)
28	CIRCUMFERENTIAL LOCATION (FILTERED)	m	DISTANCE FROM BLADE C.L., LE IS POS
29	AFT HORIZONTAL	mm	POS SIG IS SHAFT TO STBD.
30	AFT VERTICAL	mm	POS SIG IS SHAFT TO TOP
31	FORWARD HORIZONTAL	mm	POS SIG IS SHAFT TO STBD
32	FORWARD VERTICAL	mm	POS SIG IS SHAFT TO TOP
33	FFT		FAST FOURIER TRANSFORM
34	SHAFT SPEED	RPM	ALWAYS POSITIVE
35	FILTERED		ANY DESIRED CHANNEL

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TITLE:
CHANNELS AVAILABLE IN THE
"ANALYZE 4– 1 PROGRAM

TABLE 4.1 - 1

The peak blade force is defined as the largest excursion of the blade force from the mean. The direction of the peak force is "1" for a force pushing the blade tip ahead, and "-1" for a force pushing the blade tip astern.

The "ANALYZE4_1" program also contains software corrections for errors which were found in the raw data. Two of the main problems were the presence of erroneous data for the last half second or so of the recorded data, and individually bad data points. The "erroneous data" at the end of the data was caused by a software problem which caused data to be "left over" from the previously recorded test. Individual bad points tended to be caused by problems with the computer's memory or bad spots on the computer disks . The problem of erroneous data was repaired by programming the "ANALYZE4_0" version of the program to recognize the erroneous data and then to determine the number of good scans for each test. The number of good scans for each test which has less than 7,000 readings per channel is hard-coded into the "ANALYZE4_1" version of the program. In this way only actual good data is used by the "ANALYZE4_1" program.

The individually bad data points were noted during the analysis of the data. A list of the bad data points for each test is also contained in the "ANALYZE4_1" program. The bad data points were corrected by setting the value of the reading of that point equal to the value of the first good data point preceding the data glitch.

The statistics produced by the "ANALYZE4_1" program were placed on six separate disks. A program called "STATDISC4" was used to copy the files from each of these intermediate statistics disks to a single disk. A copy of the "STATDISC4" program also is presented in Appendix A, of this report.

The "STATDISC4" program deleted known bad data from the statistics so that erroneous statistics would not be used during data analysis. Examples of erroneous statistics are the readings from the shaft thrust strain-gauges which started to drift after test 206. Manually obtained statistics were also added to the statistics disk using this program.

The second program used for data analysis, "STATALYZE8", uses the information contained on the single statistics disk to produce plots of test statistics. A copy of the "STATALYZE8" program is given in Appendix A. A listing of the channels of data available within the "STATALYZE8" program is given in Table 4.1-2

CHAN #	CHANNEL DESCRIPTIONS	UNITS	COMMENTS
1	BLADE CENTRE BENDING	MPa	POS SIG FOR TIP BENDING FORWARD
2	BLADE TRAILING EDGE TORQUE	MPa	POS SIG FOR TRAIL. EDGE BENDING FWD
3	BLADE LEADING EDGE BENDING	MPa	POS SIG FOR TIP BENDING FORWARD
4	BLADE CENTRE TORQUE	MPa	POS SIG FOR TRAIL. EDGE BENDING FWD
5	BLADE TRAILING EDGE BENDING	MPa	POS SIG FOR TIP BENDING FORWARD
6	BLADE LEADING EDGE TORQUE	MPa	POS SIG FOR TRAIL. EDGE BENDING FWD
7	SLIDING BLOCK FORCE	kN	POS SIG FOR TRAIL. EDGE BENDING FWD
8	SHAFT THRUST	kN	POS SIG IS SHAFT IN TENSION
9	SHAFT TORQUE	kN.m	POS SIG IS ENGINE DRIVING SHAFT
10	SERVO OIL PRESSURE	bar	POS CHANGE INCREASES PITCH ANGLE
11	LOC. and DIR. OF MAX FORCE	m	0=ROOT 0.945=TIP;.691=LE 0=CL CIRC.
12	AFT TOPE PROBE	mm	POS CHANGE, INCREASING SEPARATION
13	FUEL RACK	mm	POS CHANGE, INCREASING FUEL
14	TYPE OF INTERACTION		0=N/E; 1=ISOLATED; 2=MILL.; 3=BLOCKAGE
15	INTER. #, ICE or WATER, DIR.		#:0=WATER, 1=ICE: -1=AST, 0=STOP, 1=AHD
16	PROPELLER PITCH	deg	POS SIGNAL, AHEAD PITCH
17	SHIP SPEED	m/s	ABSOLUTE VALUE OF VELOCITY
18	RUDDER ANGLE	deg	POS SIG IS STBD.
19	BLADE BENDING MOMENT	kN.m	POS SIG FOR TIP BENDING FORWARD
20	BLADE SPINDLE TORQUE	kN.m	POS SIG FOR TRAIL. EDGE BENDING FWD.
21	BLADE FORCE	kN	POS SIG FOR TIP BENDING FORWARD
22	SHAFT SPEED	RPM	ALWAYS POSITIVE
23	BLADE START PEAK & DURATION	deg	0 DEG. TOP 90 is INBOARD, SINGLE BL
24	TQ. ENEG. & DUR.; FORCE AREA		INT. ENEG KJ; DUR. s: FORCE AREA kN.s
25	THRUST ST. PK. & END TIME	s	THRUST EVENT, AUTO CHOOSEN
26	THRUST ST. PK. & END THRUST	kN	THRUST EVENT, AUTO. CHOOSEN
27	THRUST ST. PK. & END TORQUE	kN.m	THRUST EVENT, AUTO. CHOOSEN
28	TORQUE ST. PK. & END TIME	s	TORQUE EVENT, AUTO. CHOOSEN
29	TORQUE ST. PK. & END THRUST	kN	TORQUE EVENT, AUTO. CHOOSEN
30	TORQUE ST. PK. & END TORQUE	kN.m	TORQUE EVENT, AUTO. CHOOSEN

TITLE: LISTING OF DESCRIPTIONS OF CHANNELS OF DATA AVAILABLE ON STATISTICS DISK

TABLE 4.1-2

Each of the 30 channels has up to 5 columns of statistics associated with it, as shown in Table 4.1-3. The data in all columns of channels numbers 14, 15, 23 and the first two columns of channel 24 were determined through manual observations of the data. The rest of the data-runs were produced automatically by the "ANALYZE4_1" program.

The data contained in channels 14 and 15 are as described in section 4.2. Channel 23 is a listing of the position of the centerline of the instrumented propeller blade at the start and at the peak of the event on that blade. Channel 23 also records the duration of the event for that blade. These three readings are given in terms of the degrees of rotation of the blade. These measurements were determined using the "STATISTICS" keys in the "ANALYZE4_1" program, by manually viewing the traces for each event.

The first two columns of channel 24 were determined by viewing the shaft torque signal for each test. The interaction energy is a measure of the area under the shaft torque verses time curve, minus the area due solely to hydrodynamic variations, during the time the event can be observed on the torque signal. Some of the areas are negative due to the choice of the start and end points.

The "STATALYZE8" program has the capacity to produce either histograms or X-Y plots for the statistical data. The plots may be subject to a maximum of ten logic tests based on any of the statistical data. It is also possible to obtain a listing of the test numbers which pass the logic tests. An example of a logic test is to list blade force means verses shaft thrust means, subject to the condition that shaft torque > 140kN * m.

The "STATALYZE8" program has other utility functions. It can be used for fitting a best-fit straight line to the X-Y data and for calculating the mean and standard deviation values of histograms.

4.2 Categorization of the 343 Ice/Propeller Interaction Tests

The determination of the type of event was a subjective decision made by the researchers, since the computer could not recognize event types. There may also be more than one type of interaction during the 6.81 second window recorded. The determination of the type of event was based upon the following criteria: The variation in the torque or thrust signal must be greater than 25 per cent of the mean signal; Isolated events

CHAN			COLUMN DESCRIPTIONS			UNITS
#	ONE	TWO	THREE	FOUR	FIVE	
1	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	MPa
2	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	MPa
3	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	MPa
4	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	MPa
5	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	MPa
6	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	MPa
7	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	kN
8	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	kN
9	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	kN.m
10	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	bar
11	RADIAL LOC.	CIRC. LOC.	FORCE SENSE			m
12	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	mm
13	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	mm
14	FIRST TYPE	SECOND TYPE	THIRD TYPE			
15	INTERRUPT #	ICE or WATER	SHIP DIRECT.			
16	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	deg
17	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	m/s
18	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	deg
19	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	kN.m
20	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	kN.m
21	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	kN
22	MIN VALUE	MAX VALUE	MEAN VALUE	MIN-MEAN	MAX-MEAN	RPM
23	START ORIENT.	PEAK ORIENT.	DURATION			deg
24	INT. ENERGY	DURATION TIME	BL. FORCE AREA	IPI POWER kW		
25	START TIME	PEAK TIME	END TIME	PEAK-START	DURATION	s
26	START THRUST	PEAK THRUST	END THRUST	PEAK-START	END-PEAK	kN
27	START TORQUE	PEAK TORQUE	END TORQUE	PEAK-START	END-PEAK	kN.m
28	START TIME	PEAK TIME	END TIME	PEAK-START	DURATION	s
29	START THRUST	PEAK THRUST	END THRUST	PEAK-START	END-PEAK	kN
30	START TORQUE	PEAK TORQUE	END TORQUE	PEAK-START	END-PEAK	kN.m

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TITLE: DESCRIPTIONS OF COLUMNS OF DATA AVAILABLE ON THE STATISTICS DISK FOR EACH CHANNEL OF DATA

TABLE 4.1-3.

occur when the shaft torque increases by more than 25 per cent of nominal, but the shaft torque does not rise to a plateau level; Milling occurs when the torque level rises to a plateau level and stays there for more than half a second during an event, and; blockage occurs when there is an increase in the hydrodynamic variation of the shaft thrust with no increase in the shaft torque. These guidelines are very general and in addition almost every event has aspects of more than one type of event present. Therefore the classification of the events depends greatly on the person making the judgement.

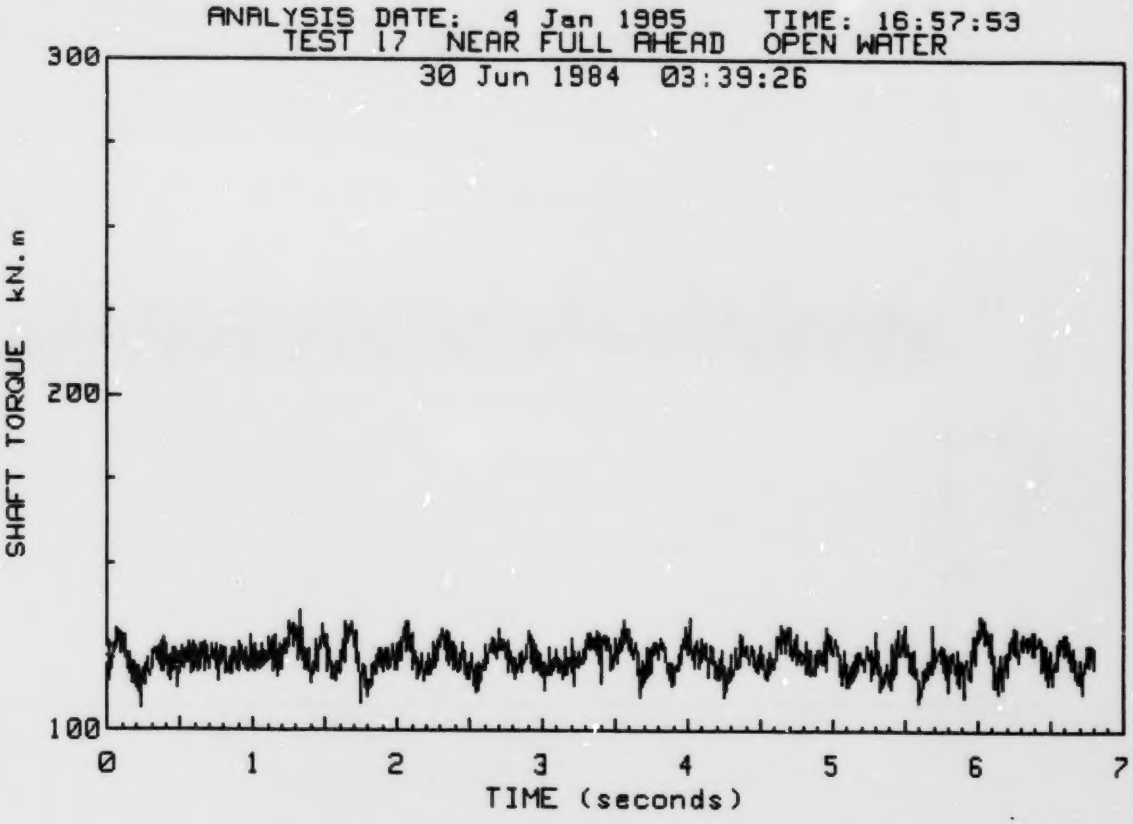
Examples of the shaft torque and thrust waveforms for a record with no event are given in Figures 4.2.1 and 4.2.2. The variation in these waveforms is due to the normal hydrodynamic variation in open water.

Figures 4.2.3 and 4.2.4 are examples of the torque and thrust waveform during an isolated event. Although the duration of the interaction is a half second long, this event is not classified as milling because the torque does not rise to a plateau level and stay there fore more than one half of a second.

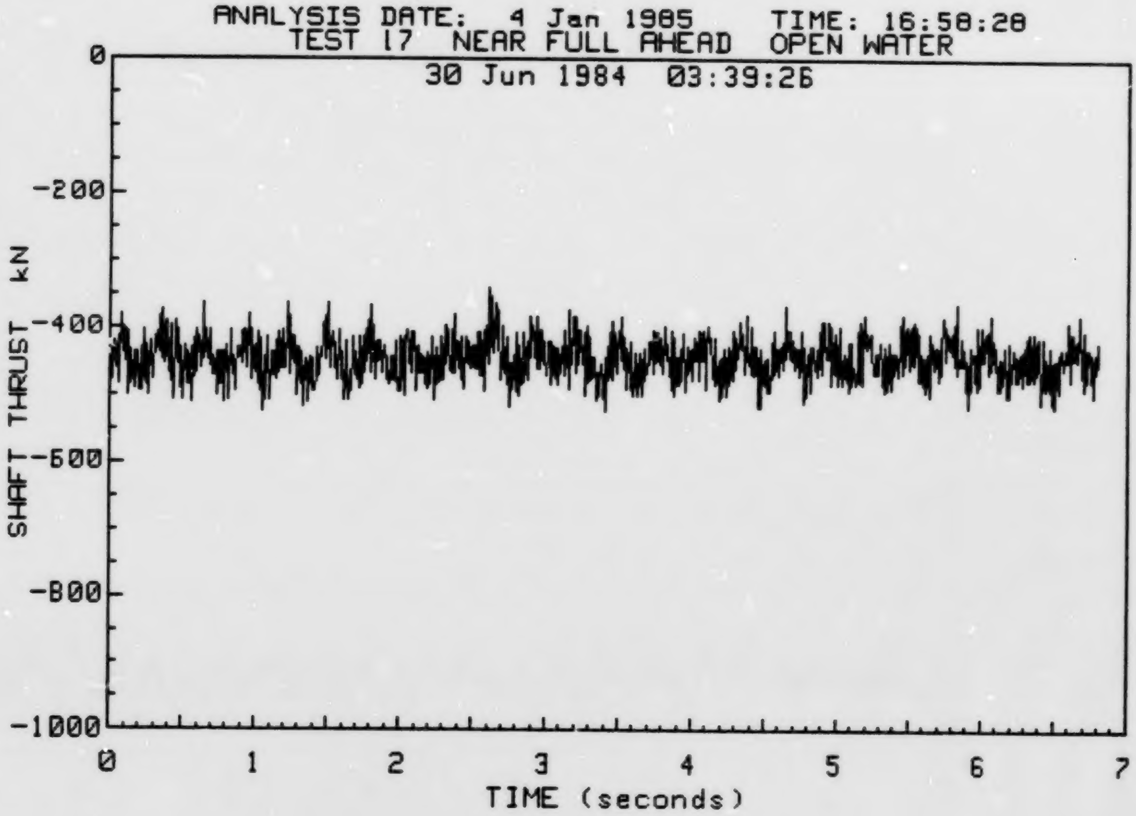
Figures 4.2.5 and 4.2.6 are examples of the shaft torque and thrust waveform during a milling event. This event is different from the previously shown isolated event case in that the mean torque rises to a new level for more than one half second, during the interaction.

Figures 4.2.7 and 4.2.8 are examples of the shaft torque and thrust when the nozzle is partially blocked by a piece of ice. It can be seen that the change in the shaft torque is no greater than the hydrodynamic variation in the torque when the ship is operating in open water. This indicates that none of the blades are actually contacting any ice. The variation in the shaft thrust is greater than the variation during open water operation. This is caused by the water flow through the nozzle being disturbed by a block of ice trapped in front of the nozzle.

The torque and thrust signals plotted in Figures 4.2.9 and 4.2.10 (Test No. 163) are included to show that the ice can interact with the blades in different ways, under the same operating conditions. At approximately 2 seconds, the ice causes an increase in the thrust signal variation, with a relatively small increase in the shaft torque variation. At 4.5 seconds another ice/propeller interaction occurs, however this time the increase in the shaft torque is large, while the increase in shaft thrust is smaller. The variation in shaft responses for these two events, are due to the differences in the location at



CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: SHAFT TORQUE SIGNAL, WHEN THERE IS NO EVENT
		FIGURE No. 4.2-1



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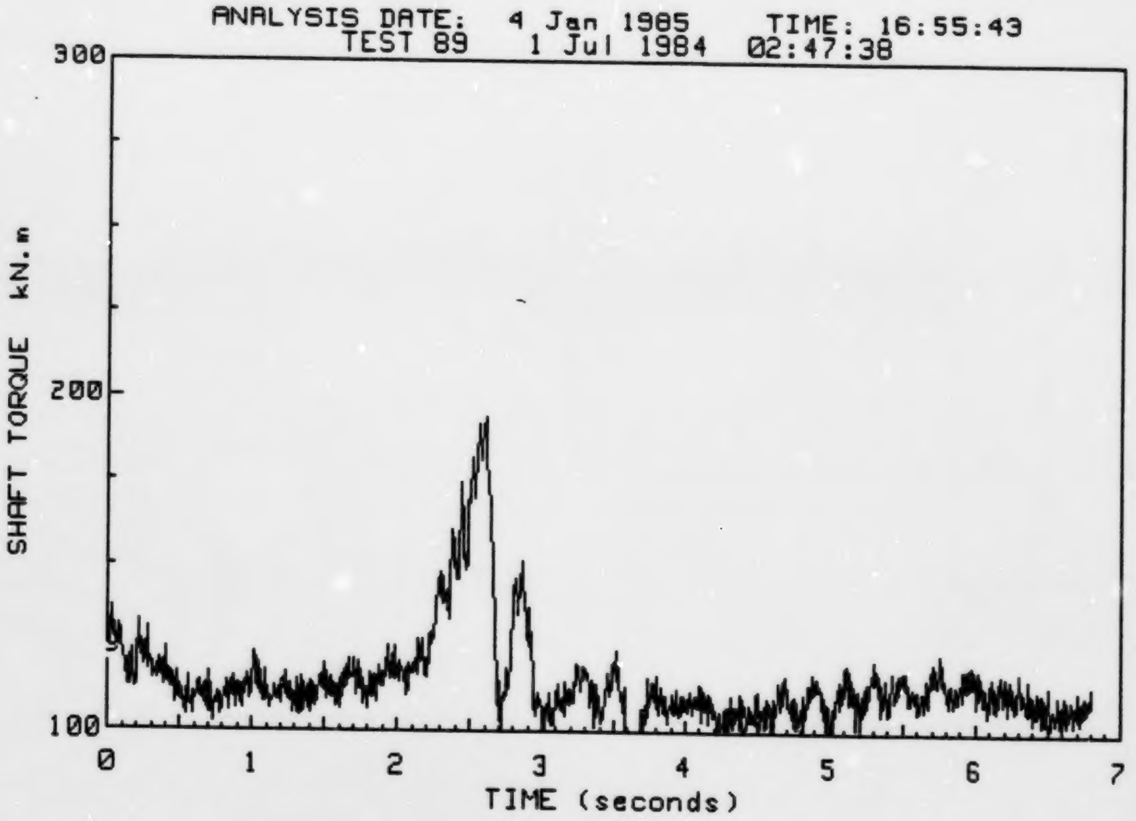
MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **SHAFT THRUST SIGNAL, WHEN THERE IS NO EVENT**

FIGURE No. 4.2-2



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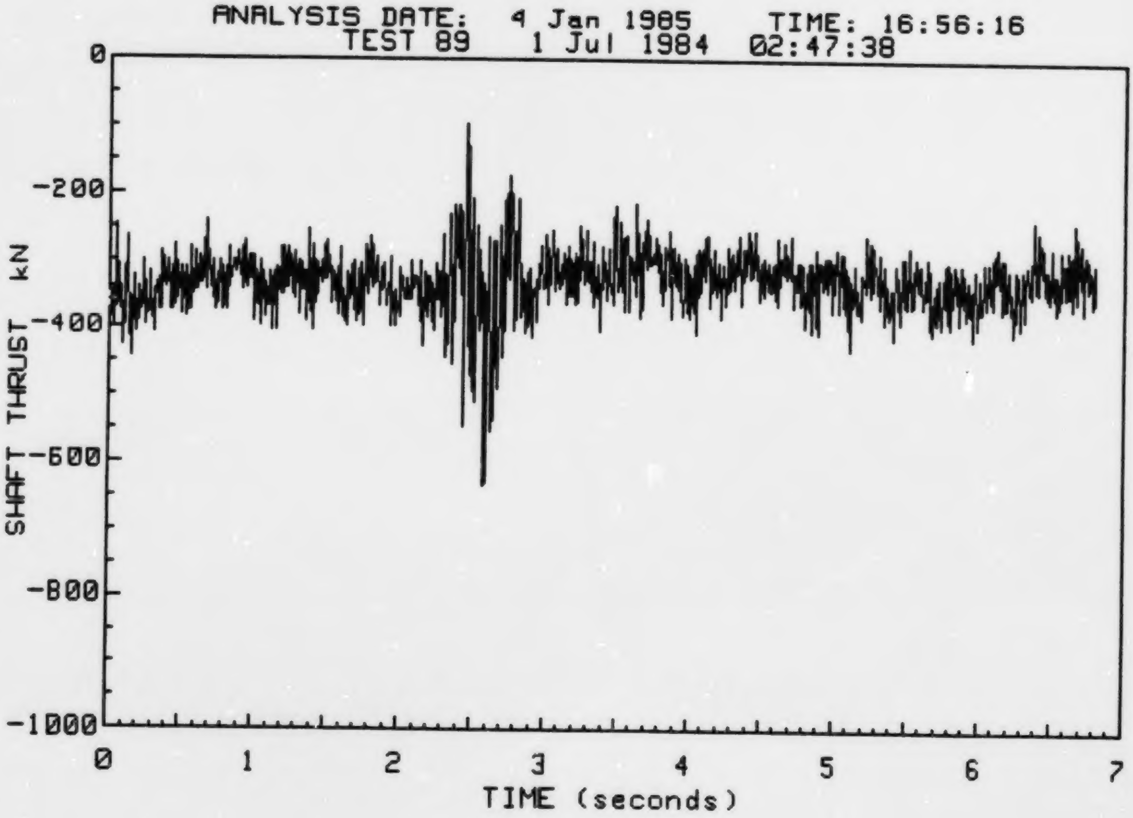
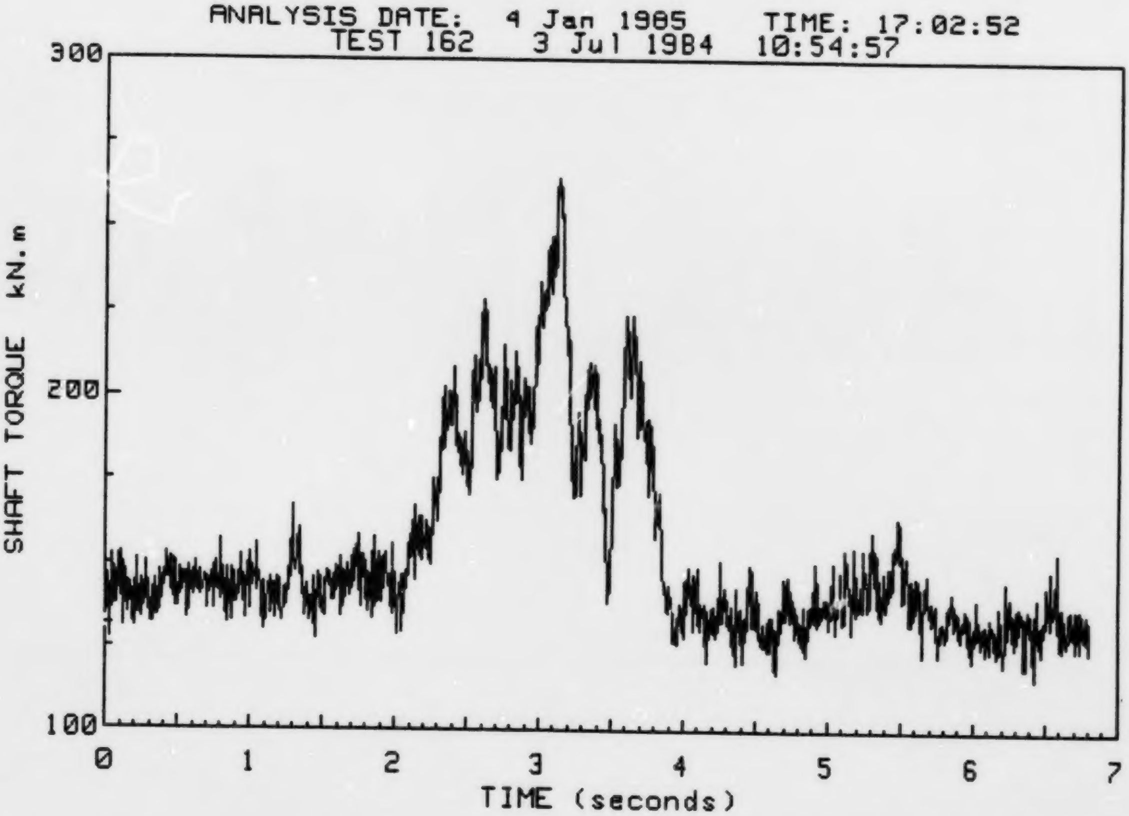
MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
SHAFT TORQUE SIGNAL, DURING A SINGLE ISOLATED EVENT

FIGURE No. 4.2-3



CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **SHAFT THRUST SIGNAL DURING A SINGLE ISOLATED EVENT**
		FIGURE No. 4.2-4



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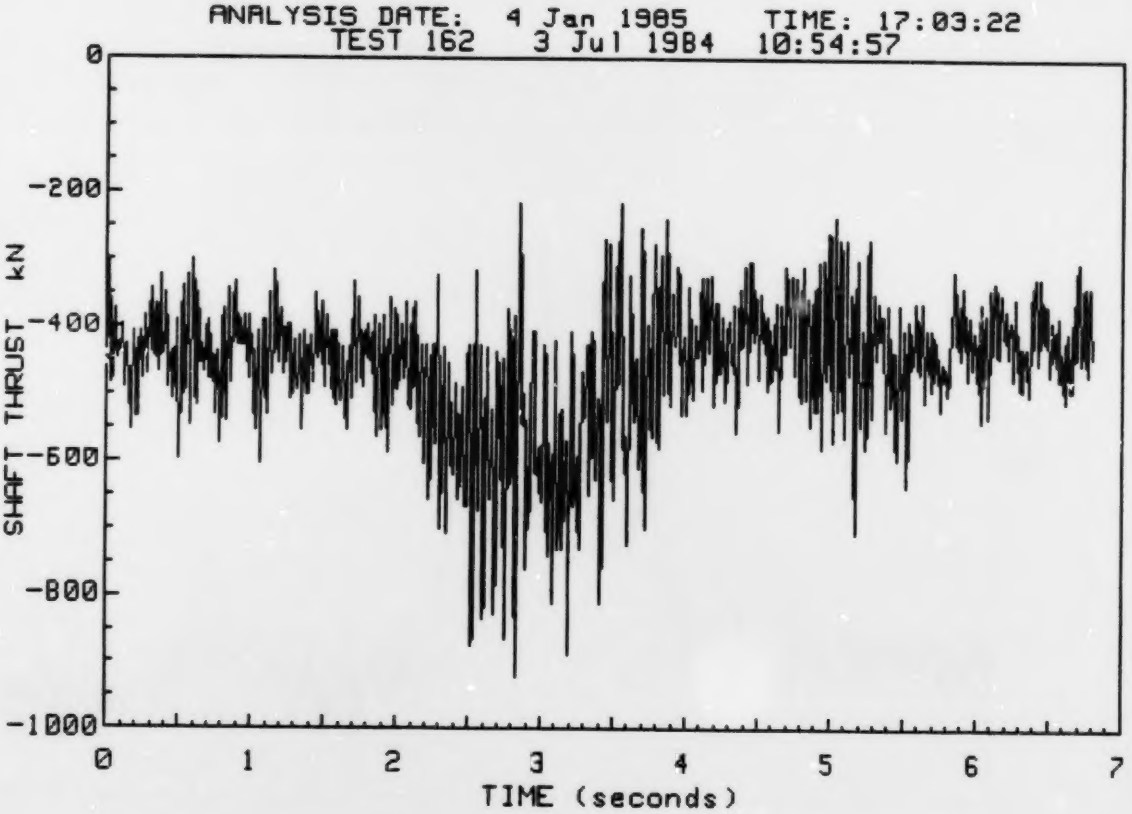
TITLE:
SHAFT TORQUE SIGNAL
DURING MILLING

FIGURE No. 4.2-5



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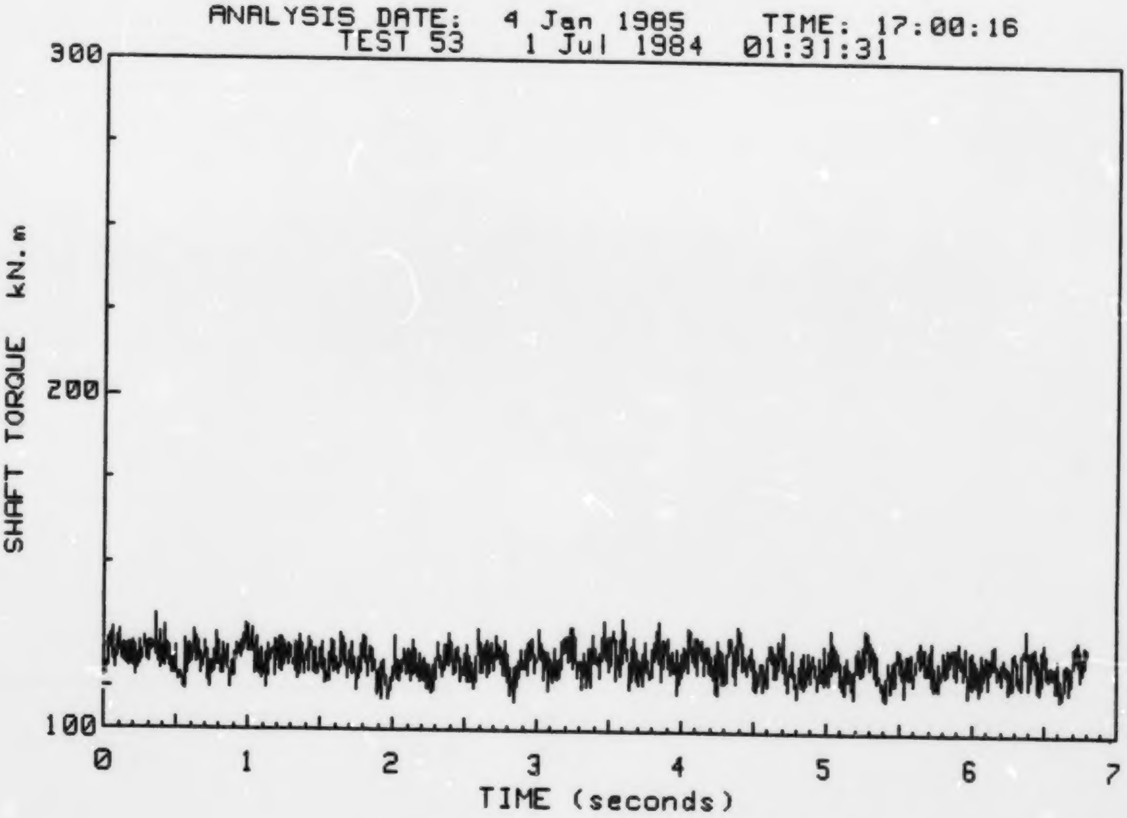
MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **SHAFT THRUST SIGNAL DURING MILLING**

FIGURE No. 4.2-6



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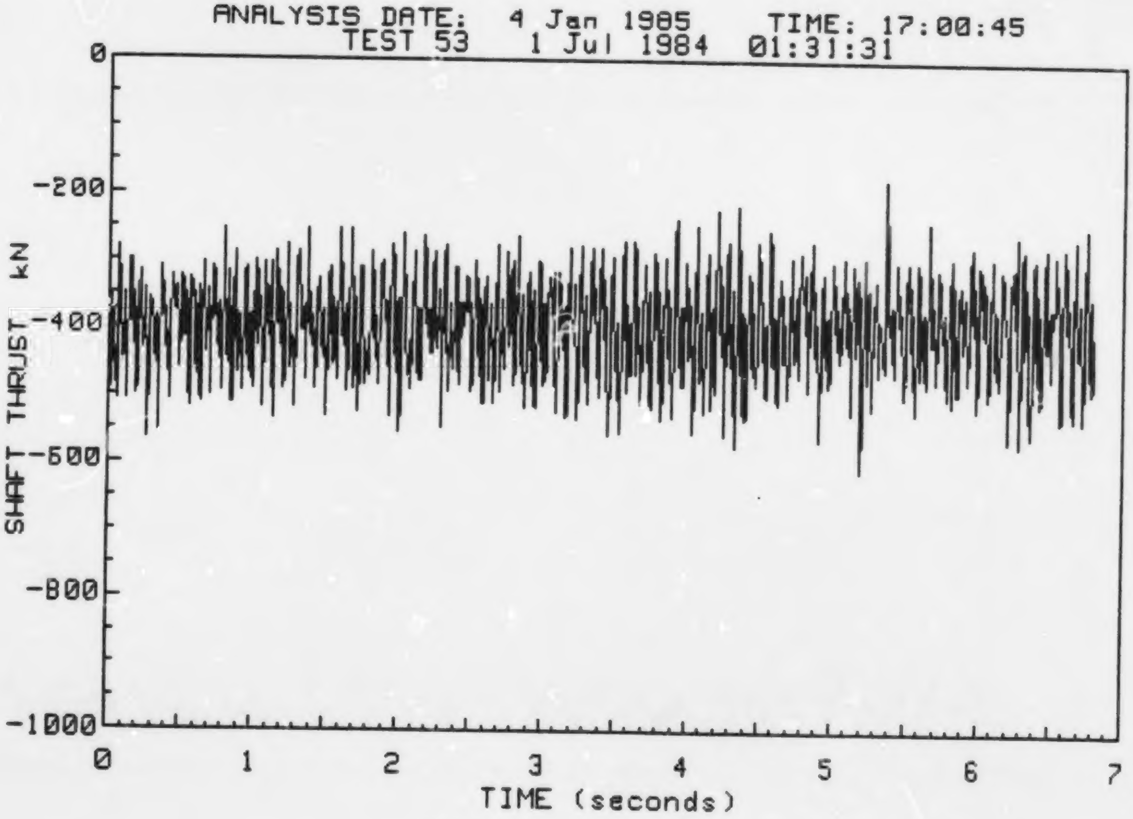
MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:

SHAFT TORQUE SIGNAL DURING NOZZLE BLOCKAGE

FIGURE No. 4.2-7

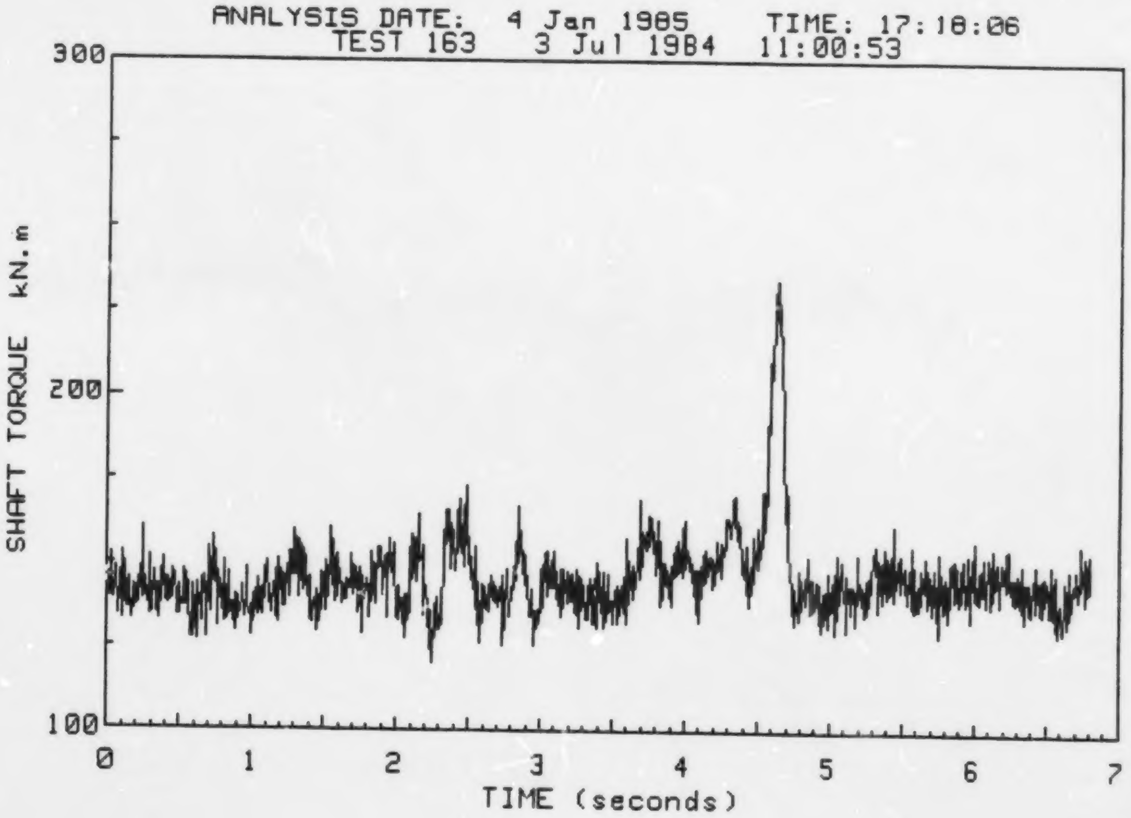


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: SHAFT THRUST SIGNAL DURING NOZZLE BLOCKAGE

FIGURE No. 4.2-8

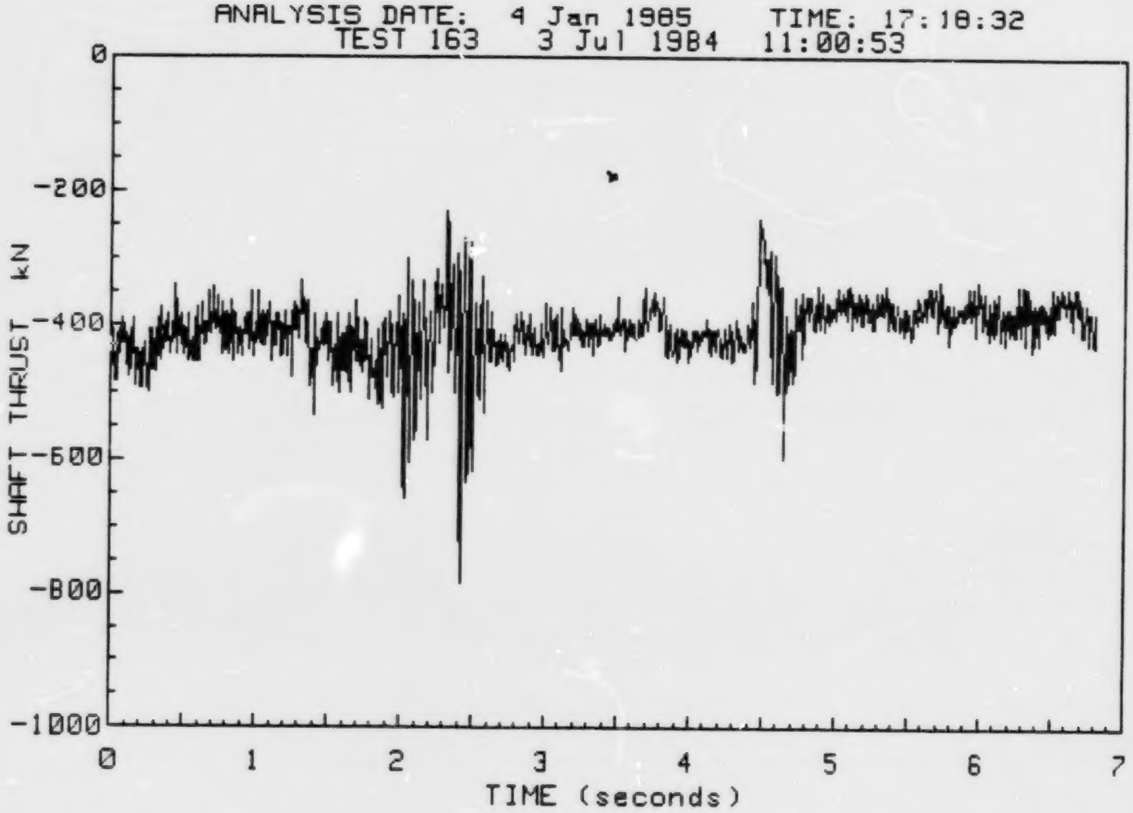


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: SHAFT TORQUE SIGNAL DURING TWO DIFFERENT TYPES OF SINGLE IMPACTS

FIGURE No. 4.2-9



CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: SHAFT THRUST SIGNAL DURING TWO DIFFERENT TYPES OF SINGLE IMPACTS
		FIGURE No. 4.2-10

which the ice hits the blade and differences in the angle at which the blade meets the ice.

The 343 events recorded by the computer were categorized in three major ways: The type of interaction; Open water or ice operation, and; Direction of travel of the ship. A listing of these categories for the 343 ice-propeller interaction tests is given in Appendix B, of this report.

An explanation of the data contained in Appendix B, is as follows:

The first column lists the events in chronological order from 1 to 343.

The second column lists the type of interaction according to the following classifications:

- O - No apparent event
- S - Isolated ice/propeller interactions
- M - Ice milling
- B - Nozzle blockage

The distribution of the type of events observed is as follows:

- No event - 41[3]
- Isolated events - 151
- Ice milling - 82
- Nozzle blockage - 66

A dash is used to represent "no data available" in the table.

The third column is the interrupt data, which is the sum of the code numbers of the channel or channels which caused the analogue event detector to trigger. The codes for the individual channels are as follows:

- Manual trigger i.e. no event - 0
- Blade centre bending - 1
- Blade trailing edge torque - 2
- Blade leading edge bending - 4
- Blade centre torque - 8
- Blade trailing edge bending - 16
- Blade leading edge torque - 32
- Sliding block force - 64

[3] There are tests with no "Events" due to either: Recordings made to test the equipment; Manual triggers to obtain open-water conditions, and; Recordings made while finding the optimum trigger level settings.

- Shaft thrust - 128, and
- Shaft torque - 256

The fourth column gives an "I" for when the ship is operating in ice, and an "O" for open water operation. These operating conditions are determined from field notes made during the testing period.

The fifth column is the direction of travel of the ship: "F" for ahead "O" for stopped, and; "R" for astern. The direction of movement can be determined in most cases from the propeller pitch, however there were some tests during which the propeller pitch setting indicates a direction of travel opposite to the actual direction of ship movement.

The sixth and seventh columns are the date and time of the test.

The eight column is a list of comments which are stored with the data, or interesting events and problems with the data which were noted during review of the data.

The categorization of the 343 tests is included in the data contained on the statistics disk. These statistics can be read by the program "STATALYZE8". The format of the event categorizations on the statistics disk are slightly different than the listing in Appendix B. The event type is stored in channel 14 for each event and are given numbers as follows:

- No event - 0
- Isolated peak - 1
- Milling - 2
- Blockage - 3

The interrupt data is stored as channel number 15, column 1 data, using the same codes as given in Appendix B,.

Open water operation is listed as "0" in channel number 15, column 2 data, while operation in ice is listed as "1".

The direction of travel of the ship is listed in channel number 15, column 3 data as: "1" for ahead; "0" for stopped, and; "-1" for astern.

As an aid to choosing the most interesting events, and to show that there does not necessarily exist correlations between the extreme excursions of the various signals, Table 4.2-1 shows a summary of the most

TEST NO.	NEG. SLIDING BLOCK	POS. SLIDING BLOCK	NEG. THRUST	POS. THRUST	TORQUE	NEG. BENDING MOMENT	POS. BENDING MOMENT	NEG. SPINDLE TORQUE	POS. SPINDLE TORQUE	NEG. FORCE	POS. FORCE
5	1										
8											5
46	2										
49									6		
54		2							3		
72											1
83								1			
102				1		1				1	
103				2						3	
105										2	
117			3		1						
127			2								
128			5								
129			4								
130			1								
135				6							
138					5						
141					3						
143				3							
144				4							
145				5							
165							2		1		2
166		3									
170								2			4
178		1							4		
186					2						
223							4				6
239									2		
285							6				
297									5		
299		4									
313					4		3				
314								3			
320							5				
328					6						
336							1				3

CANADIAN
MARINE
DRILLING
LIMITED

MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE:
RANKING OF
INTERESTING PARAMETERS

TABLE 4.2-1

significant events. The events are ranked from 1 being the largest excursion from the mean, to 6 being the sixth largest excursion. There are not 6 significant events available for all signals.

4.3 Detailed Description of Signals Collected During A Single Test

4.3.1 Introduction

In order to acquaint the reader with an overview of all the signals gathered during a single test, one has been chosen for a detailed discussion. The description is presented in this subsection.

Test 42 was selected as an appropriate example because it had most of the available signals working properly. Also, the variations in the signals provided meaningful insights into the workings of and the interrelations between the different drive train components. As well as describing the significance of the recorded signals, it is possible to demonstrate some of the capabilities for analysing the results which were engineered into the project.

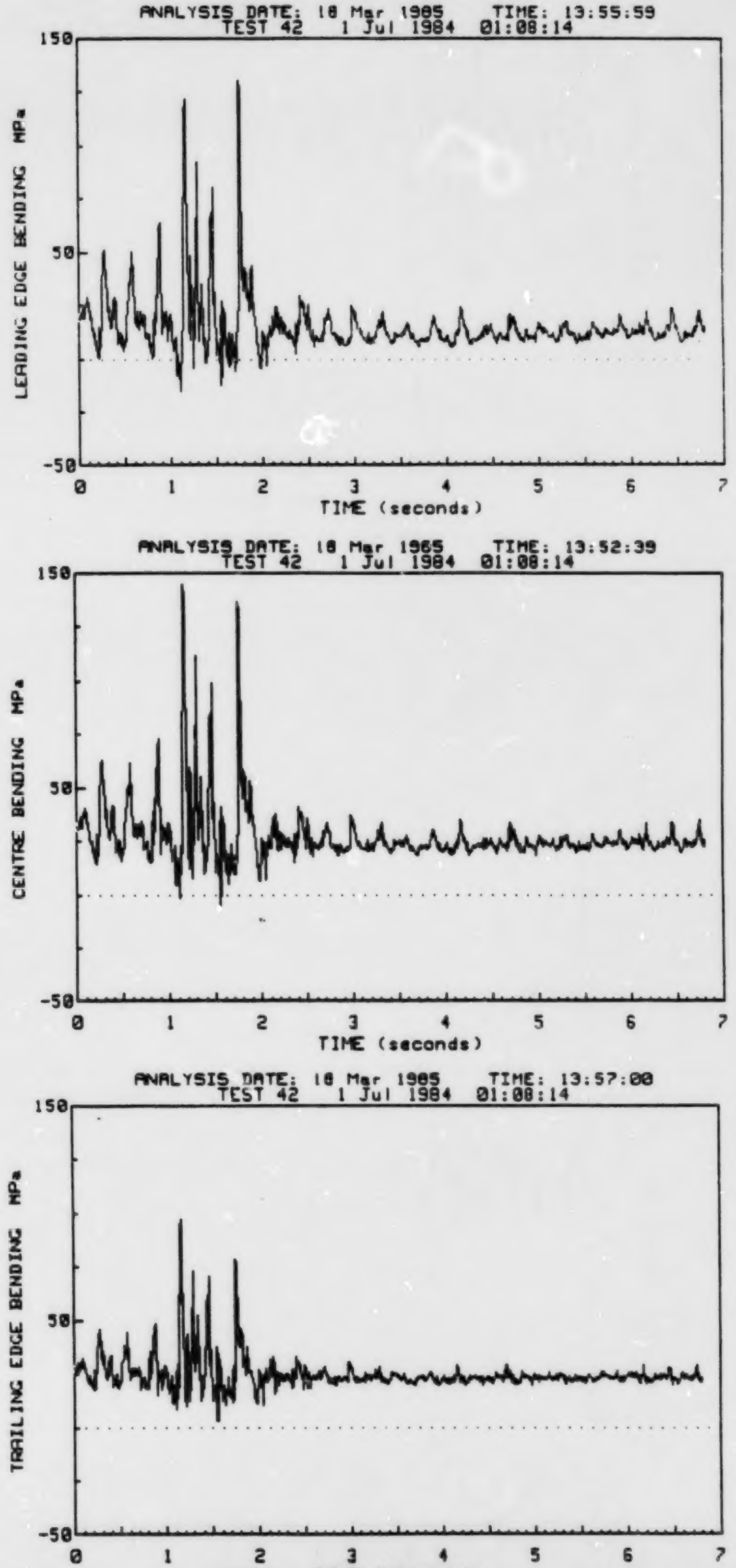
The plots presented in Figures 4.3.1-1 to 4.3.1-10 were all produced using the "ANALYZE4_1" software program.

4.3.2 Blade Bending Gauge Signals

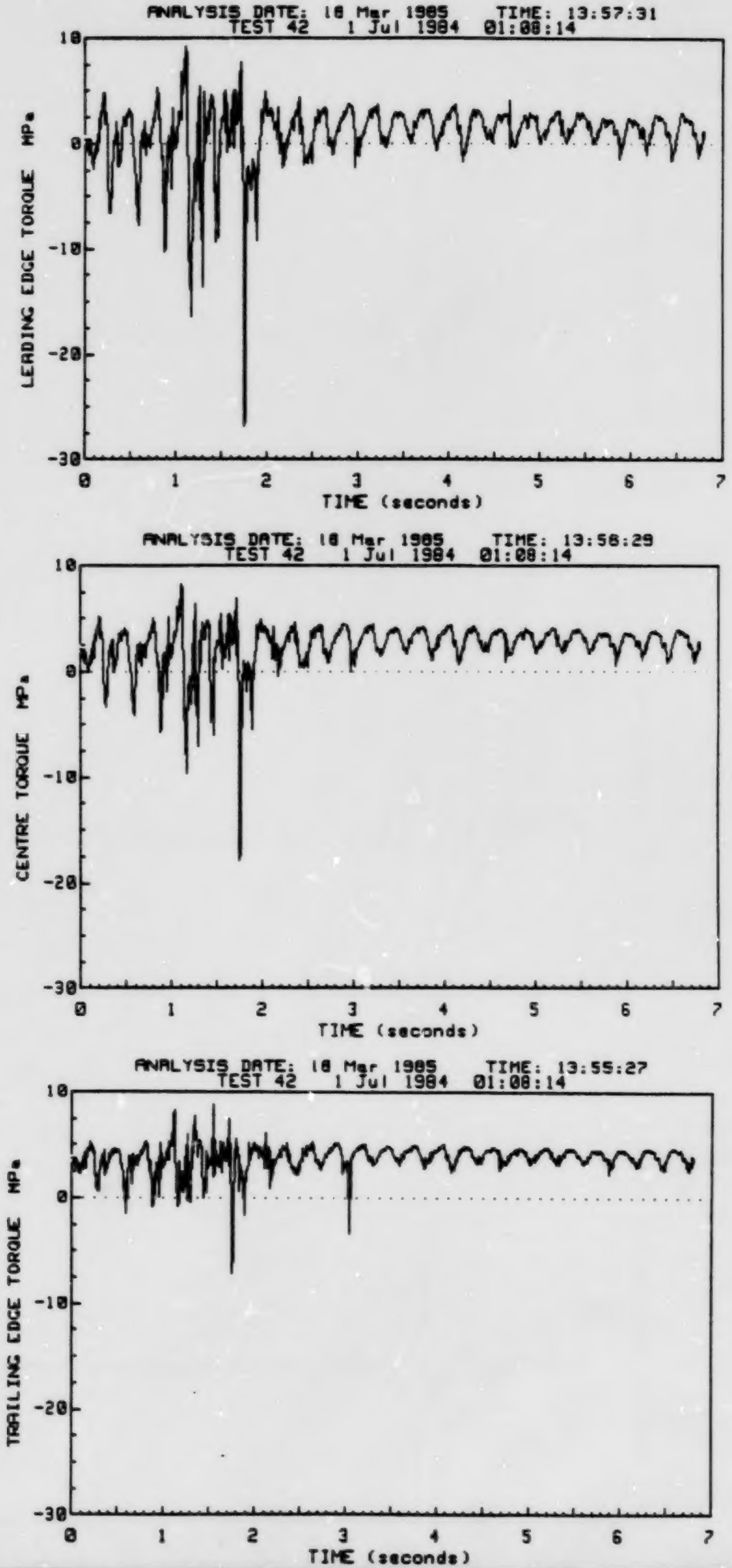
The recorded signals from the three blade bending strain-gauges, are presented in Figure 4.3.1-1. Comparisons of three blade bending signals revealed that each gauge responded to the load on the blade in the same general fashion. The amplitude of the response at any instant in time differed however. In general, the blade centre bending signal was the largest absolute amplitude of the three blade bending signals. Note that "Bending" is representing the difference of the compressive and tensile stresses experienced on the two sides of the blade, in kPa, ie. $\sigma_{Bend} = \sigma_{Comp.} + \sigma_{Tens}$.

The first two seconds of these plots, shows that the blade experienced loads which were larger than the normal hydrodynamic blade loads. Typical variations in the blade bending signals, due to hydrodynamic variations without ice/propeller interaction, are shown in the time period 2 to 6.81 seconds.

The particular type of interaction occurring for the period 1 to 2 seconds was determined to be predominately



CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** BLADE BENDING GAUGE SIGNALS
		FIGURE No. 4.3.1 - 1



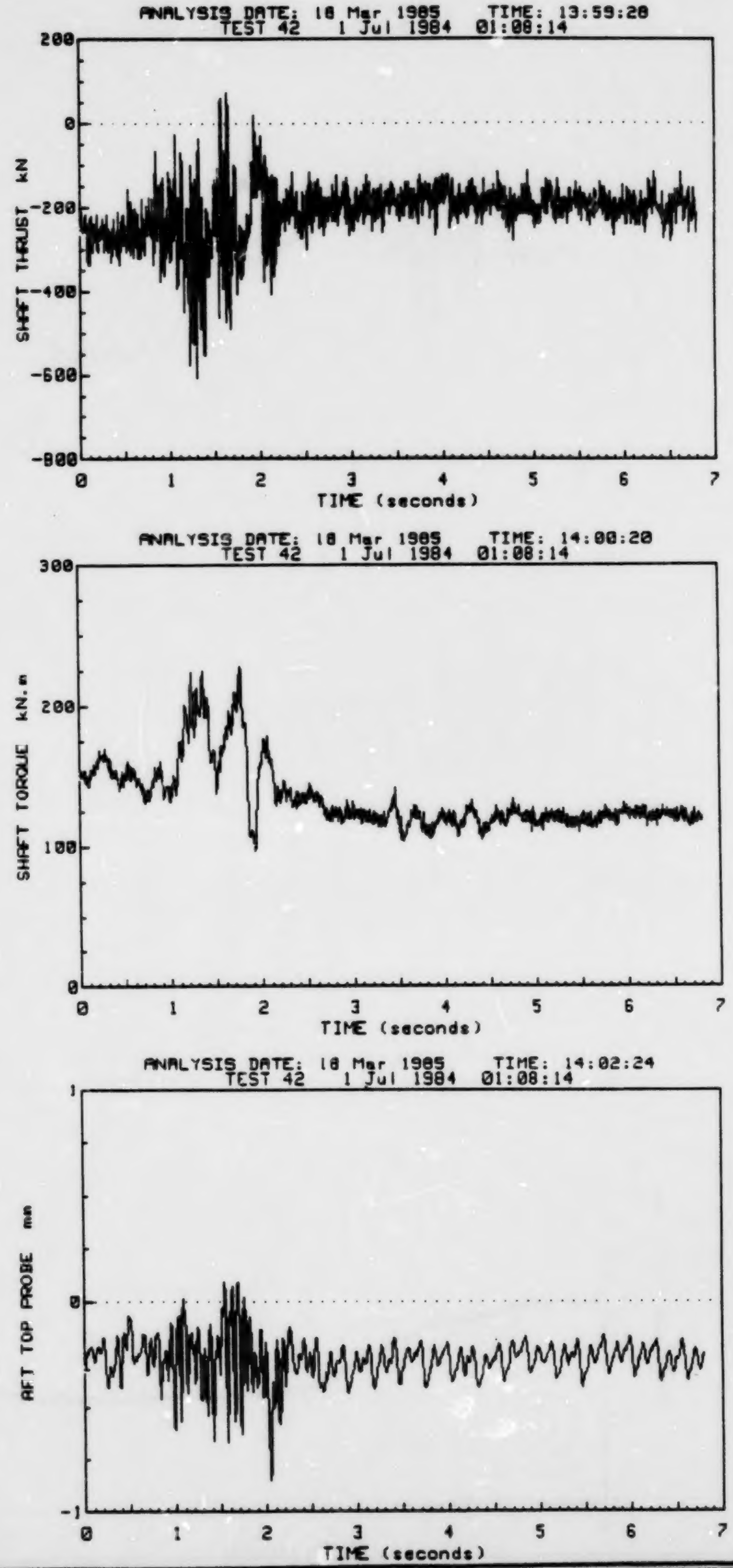
CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:

BLADE TORQUE GAUGE SIGNALS

FIGURE No. 4.3.1 - 2

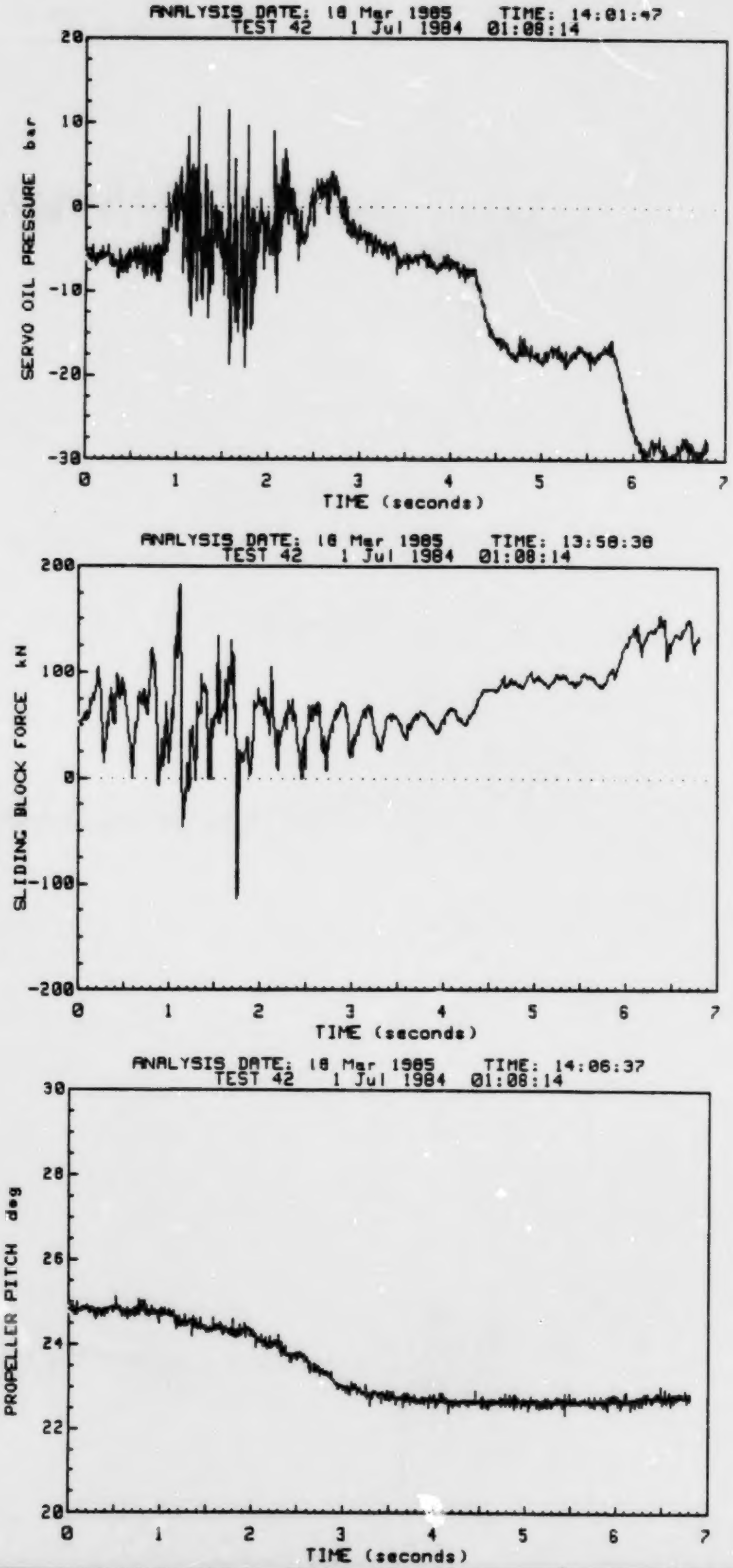


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
SHAFT THRUST, TORQUE AND AFT TOP PROBE SIGNALS

FIGURE No. 4.3.1 - 3

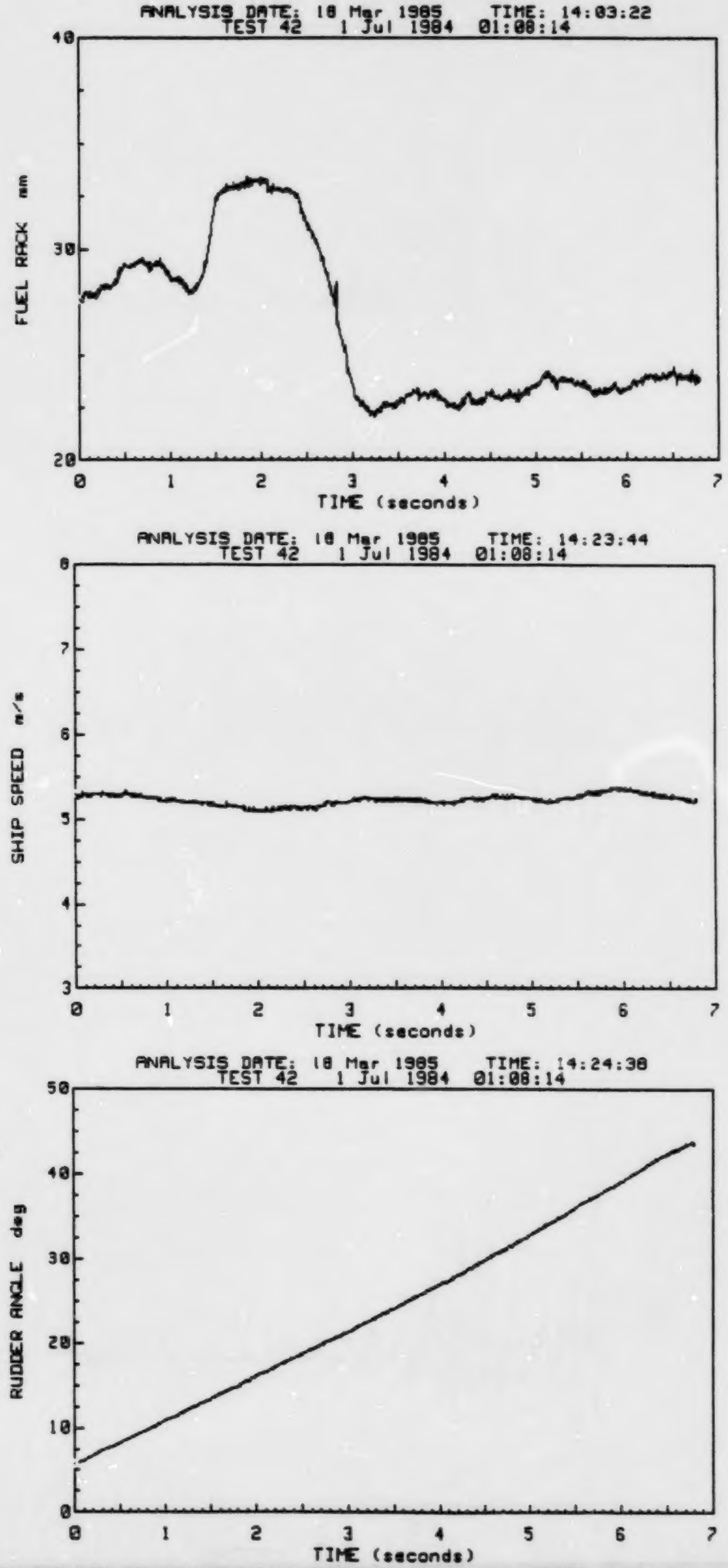


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: SERVO OIL PRESSURE, SLIDING BLOCK FORCE AND PROPELLER PITCH SIGNALS

FIGURE No. 4.3.1 - 4

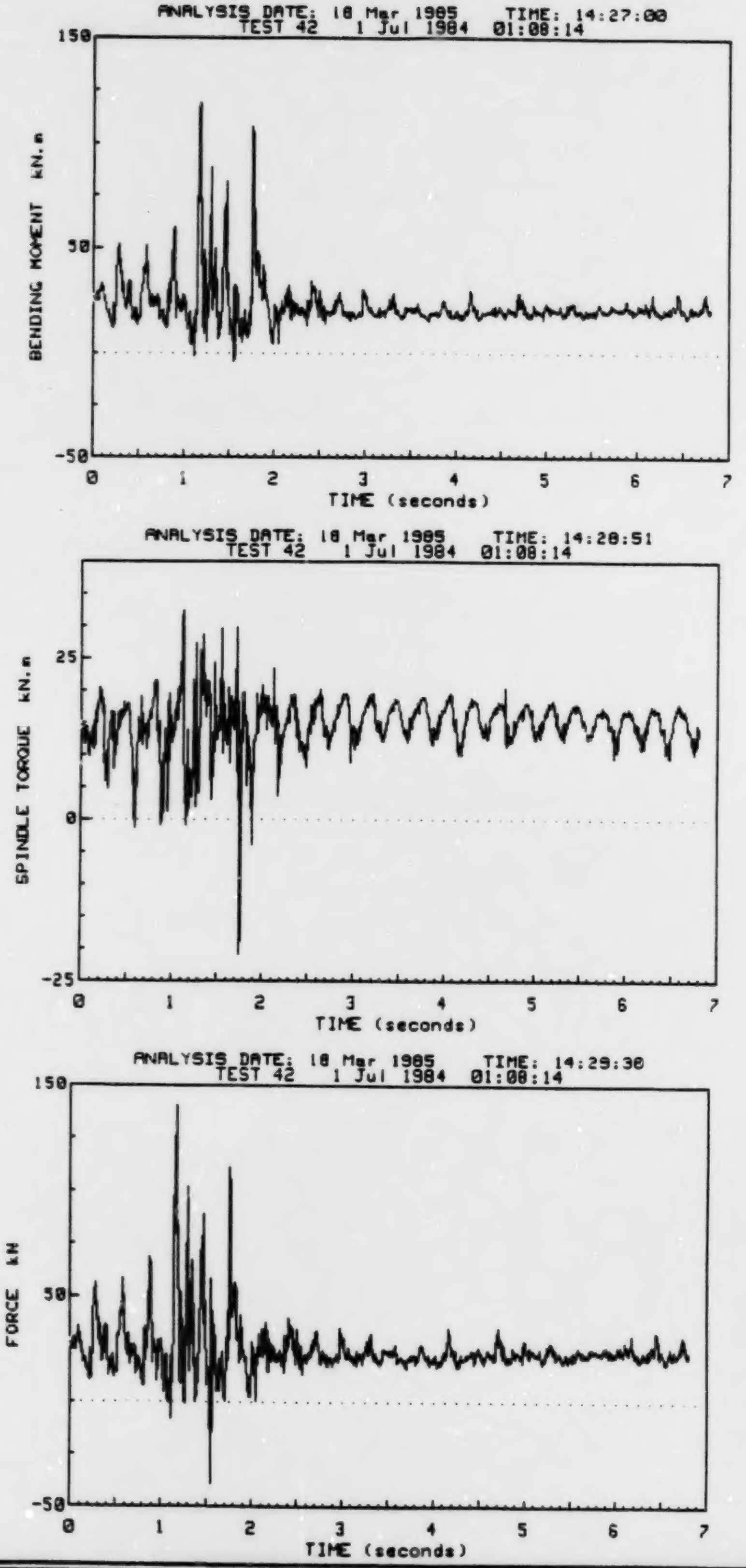


CANADIAN MARINE DRILLING LIMITED

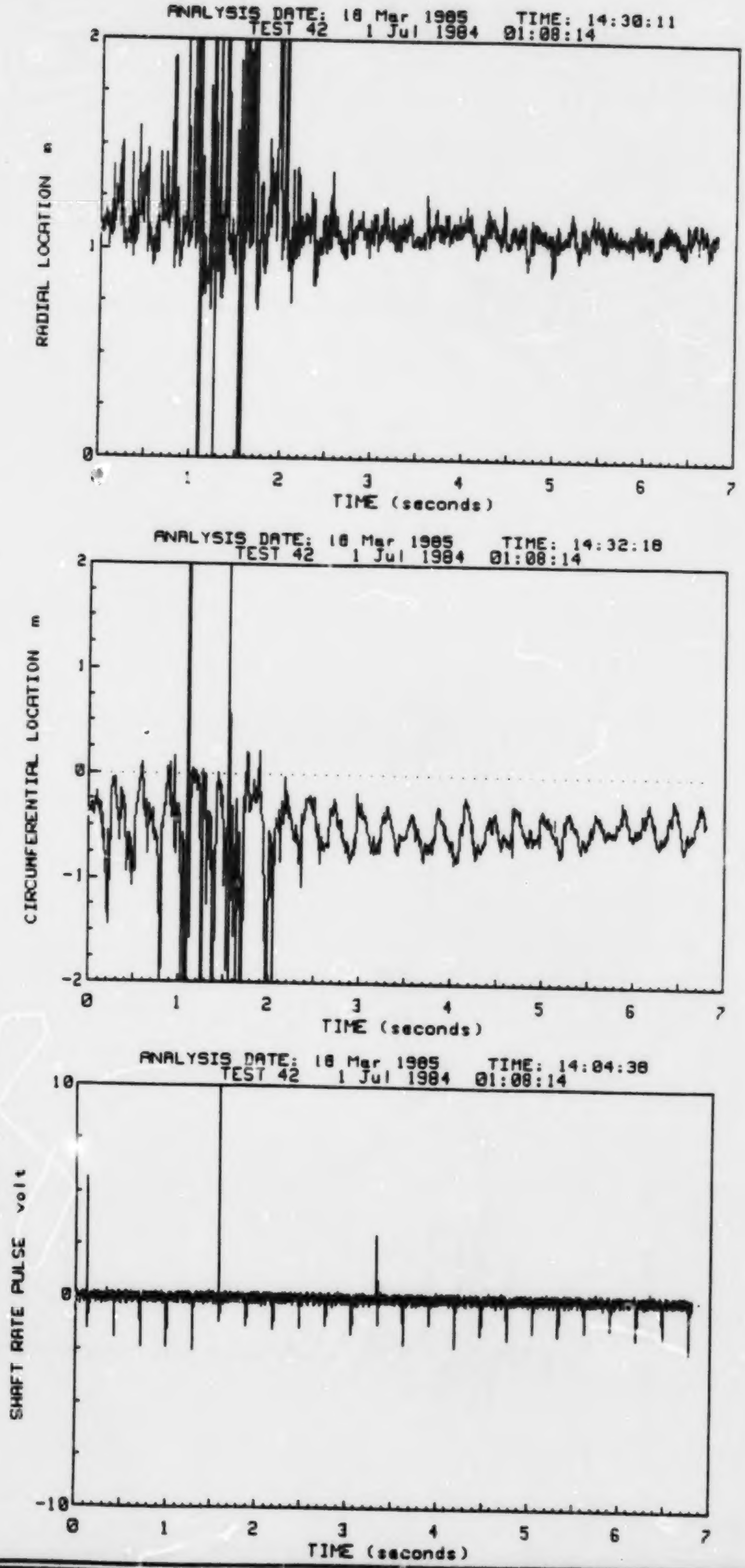
MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **FUEL RACK, SHIP SPEED AND RUDDER ANGLE SIGNALS**

FIGURE No. 4.3.1-5



CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: CALCULATED QUANTITIES OF BLADE BENDING MOMENT, SPINDLE TORQUE AND FORCE
		FIGURE No. 4.3.1 - 6

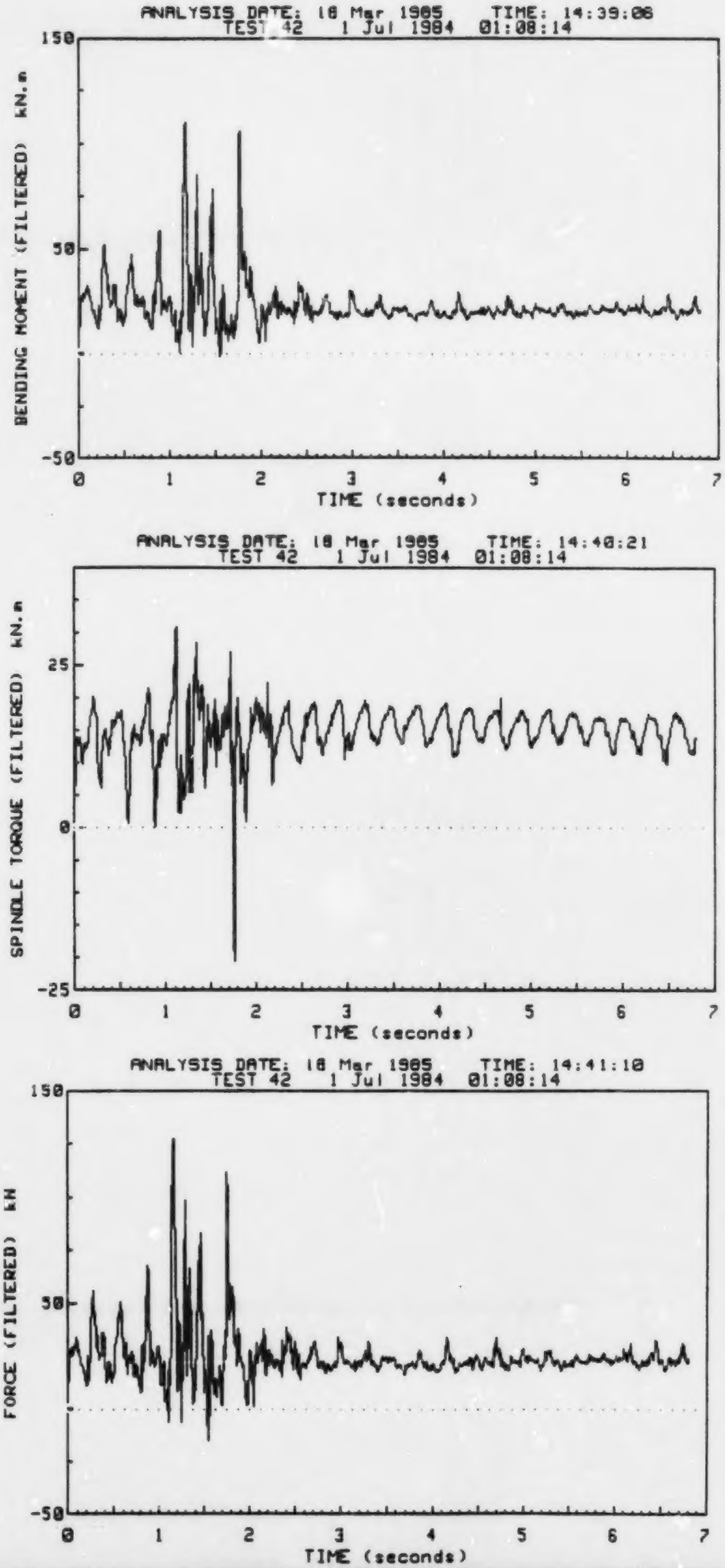


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: CALCULATED RADIAL & CIRCUMFERENTIAL LOCATION OF BLAD FORCE, AND SHAFT RATE PULSE

FIGURE No. 4.3.1-7

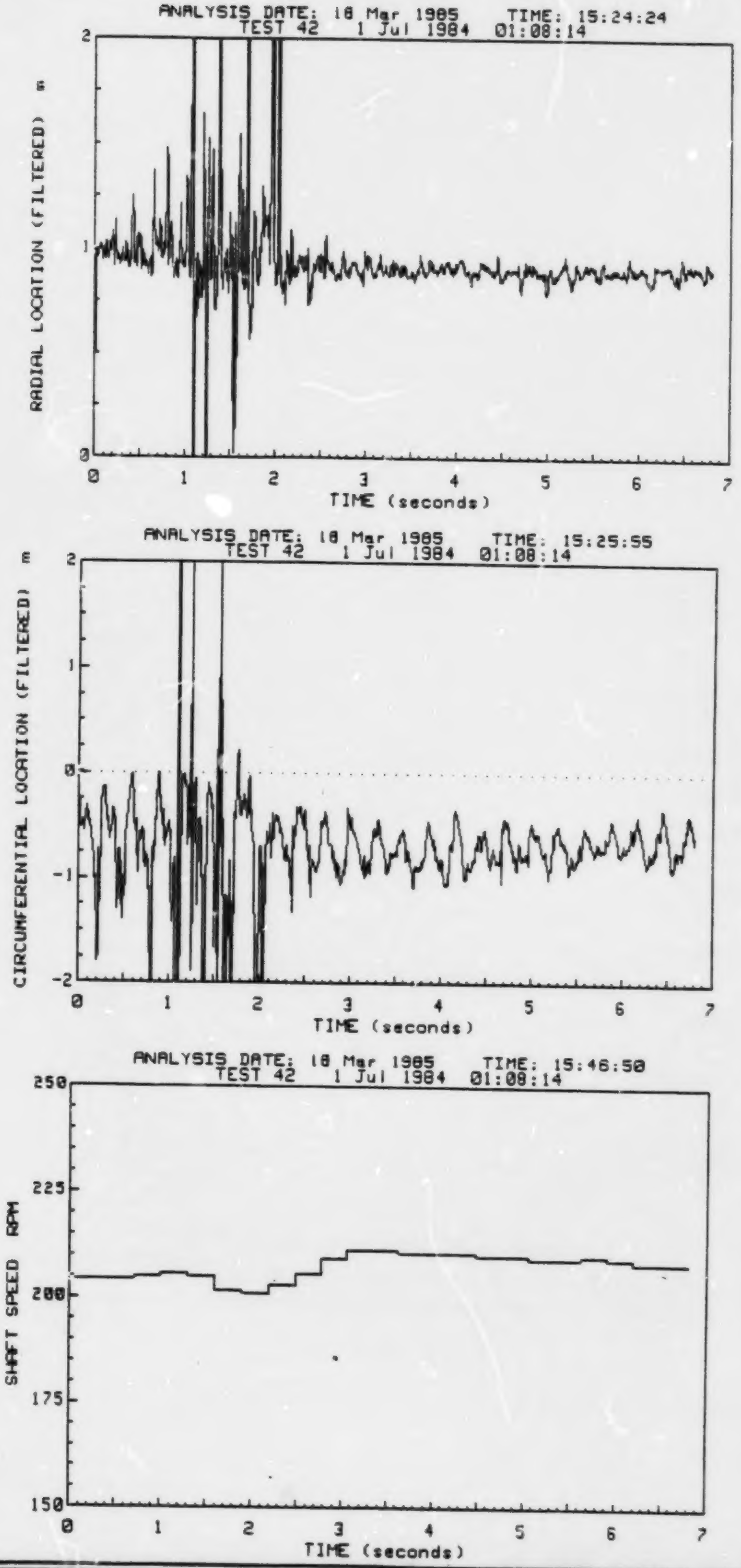


CANADIAN MARINE DRILLING LIMITED

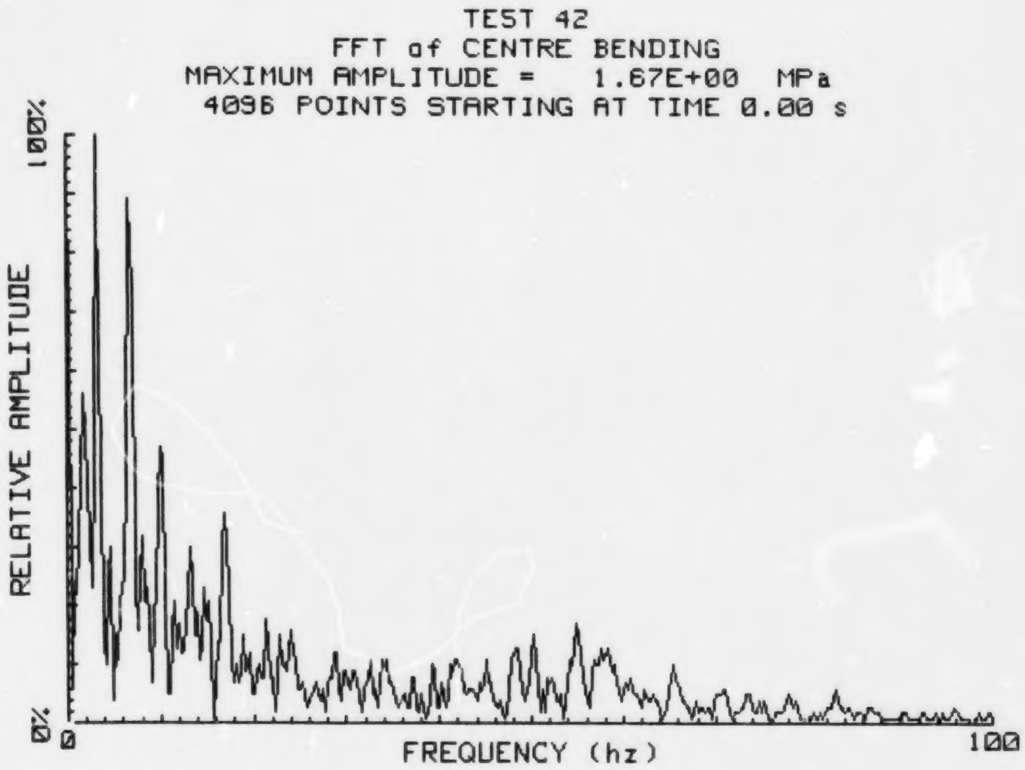
MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: FILTERED CALCULATED QUANTITIES OF BLADE BENDING MOMENT, SPINDLE TORQUE AND FORCE

FIGURE No. 4.3.1 - 8



CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: BLADE FORCE CALCULATED RADIAL & CIRCUMFERENTIAL LOCATION FILTERED, AND CALCULATED SHAFT SPEED
		FIGURE No. 4.3.1 - 9



CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **FAST FOURIER TRANSFORM OF BLADE CENTRE BENDING SIGNAL**

FIGURE No. 4.3.1 - 10

milling. There was also evidence of ice/propeller interaction in the period leading up to the ice milling event.

The large peaks during the milling were due to the fact that the bending gauges only measured the loads on a single blade. The large positive spikes in the blade bending signals indicate that each time the blade contacted the ice, the tip of the blade bent forward.

4.3.3 Blade Torque Gauge Signals

The output from the three blade torque gauge signals is shown in Figure 4.3.1-2. The ice/propeller interaction can once again be seen during the first two seconds of the sample. The signals during the time period from 2 to 6.81 seconds were of normal variation due to hydrodynamic changes during each revolution of the blade.

The blade torque gauge signals were all of the same form however, the amplitudes were all different at any instant in time. The leading edge torque signal generally had the largest absolute magnitude, as shown in this test.

The negative blade torque peaks indicate that the leading edge of the blade was being bent forward during the ice/propeller interaction, as was generally the case.

4.3.4 Shaft Thrust Signal

Figure 4.3.1-3 shows the large variations in shaft thrust which accompanied the ice/propeller interaction. The thrust variations, along with the observed blade bending signals discussed previously, indicate that during ice/propeller interactions, the force resulting from the interaction had an important axial component.

The variations in the thrust signal after the 2.5 second mark, were typical of the shaft thrust variations due mainly to hydrodynamic propeller loads.

The sense of the shaft thrust signal was such that tension in the shaft resulted in a positive signal, while compression of the shaft gave a negative signal.

4.3.5 Shaft Torque Signal

From the signal shown in Figure 4.3.1-3 for the shaft torque during this test, it can be seen that for the first second of the test, the shaft torque was close to the full power shaft torque of 150 kN*m. The subsequent dramatic rise in torque was attributed predominately to ice milling.

The assumed definition for ice milling states that the shaft torque must rise to a "plateau" level, and stay there for at least 0.5 seconds. Although the torque did not stay at the plateau level for the complete 0.5 seconds, it returned to the previous peak level quickly. The determination of the event type is therefore very subjective. Although the strict criteria were not met, the intention of the criteria was and therefore this event was classified as ice milling.

It can be seen that after the ice milling event stopped, the shaft torque returned to a mean level which was less than the mean torque before the event. This will be explained in more detail when the remainder of the recorded signals are discussed.

4.3.5 Aft Top Probe

The recorded aft top probe signal is shown in Figure 4.3.1-3. The sense of the signal was such that positive indicates increasing separation between the probe and the shaft. The variations in the probe signal up to 2.5 seconds were due predominately to the ice milling, while the probe signal variations after the 2.5 second mark were typical of the normal variations due to hydrodynamic variations without ice/propeller interactions.

4.3.7 Servo Oil Pressure

The servo oil pressure also varied due to the ice milling as shown in Figure 4.3.1-4. The change in servo oil pressure after the end of the ice milling (approximately 2.5 seconds) was due to the engine control system changing the propeller pitch in response to the change in load on the ship's propulsion system.

The sense of the servo oil pressure signal was opposite to that of the propeller blade spindle torque and sliding block signals. A positive spindle torque caused a positive load on the sliding block and negative servo oil pressure.

The servo oil pressure was not a measurement of the absolute pressure on one side of the pitch change mechanism piston, but rather a measure of the pressure differential between one side of the piston and the other. The difference in pressure between the sides of the piston was measured at the oil distribution box, and therefore was not the actual differential pressure on the piston when there was oil flow through the lines.

4.3.8 Sliding Block Force

The sliding block force reacted to the change in blade spindle torque during the milling event as shown in Figure 4.3.1-4. The mean sliding block load tended to be positive because during normal operation the load distribution on the propeller was such that a positive blade spindle torque existed. This positive blade spindle torque was large enough such that if all servo oil pressure was lost, and the propeller kept turning, the propeller pitch would change to full astern.

The rise in the sliding block load, after approximately the 4.25 second mark, was in response to the decrease in servo oil pressure. The servo oil pressure changed to cause an increase in the propeller pitch thereby increasing the torsional load on the propulsion system.

4.3.9 Propeller Pitch

The propeller pitch during this test is shown in Figure 4.3.1-4. The resolution of the pitch sensor was not large enough to show the minute changes which resulted in the changing loads on the sliding block during a single ice/propeller interaction. The response of the pitch change mechanism to the change in servo oil pressure can be seen to have started at the 1 second mark. The decreasing pitch reduced the torsional load on the drive system in an effort to keep the shaft torque within limits. Once the ice/propeller interaction passed, and the load on the engines was such that the engine torque was below the set power level, the propeller pitch started to increase and thereby increased the load on the drive train. The propeller pitch could be seen to start to increase slightly at about the 4.5 second mark.

4.3.10 Fuel Rack

The fuel rack was a measure of the rate of fuel consumption of the engine. As shown in Figure 4.3.1-5 the engine was operating in constant RPM mode. When the first ice/propeller interaction started (from 0 to 1 second), the increased load caused a reduction in shaft speed. The first response of the engine control system was to increase the fuel supply and thereby provide more torque to maintain a constant shaft RPM.

Figure 4.3.1-3 showed that at the 0.75 second mark, the torque requirement of the system was reduced and, in order to prevent the shaft from overspeeding, the fuel supply started to decrease, as shown in Figure 4.3.1-5.

The milling event caused the shaft speed to reduce again and the engine control system responded by increasing the fuel rack. The increase in shaft torque during the milling event caused the fuel rack to reach its maximum value, and the shaft speed continued to decrease. The control system therefore responded by decreasing the propeller pitch, in an attempt to reduce the required shaft torque.

At the end of the milling event, the ice load on the shaft was reduced. The pitch was also reduced, and therefore the shaft started to overspeed. The fuel rack was reduced to prevent the overspeed condition, until the propeller pitch increased enough to load down the engine.

4.3.11 Ship Speed

The ship speed during test number 42 is shown in Figure 4.3.1-5. The ship speed signal was always positive, whether the ship was moving ahead or astern. From the high ship speed and the propeller's pitch it can be deduced that the ship was travelling ahead. The high ship speed and the fact that the ship was operating in constant RPM mode further indicated that the ship was operating in open water or thin ice.

4.3.12 Rudder Angle

The plot of the rudder angle signal shown in Figure 4.3.1-5, indicates that the starboard rudder angle was changing to hard over to starboard, during test number 42. This change in rudder angle was not related to the observed ice/propeller interaction.

4.3.13 Blade Bending Moment

The blade bending moment shown in Figure 4.3.1-6 is a calculated quantity. All 6 blade gauge signals were multiplied by the [A] matrix to calculate the blade bending moment. The 3 blade bending gauge signals, however, had predominance in the calculation of the blade bending moment. This predominance of the blade bending gauge signals in the calculation, could be observed by comparing the calculated blade bending moment with the blade centre bending signal shown in Figure 4.3.1-1. The positive peaks during he ice milling indicated that the tip of the blade was bent forward during each ice/propeller interaction.

The calculated blade bending moment was the bending moment at the root of the blade, the location of which corresponds to 0.37 relative radius.

4.3.14 Blade Spindle Torque

The blade spindle torque shown in Figure 4.3.1-6 was calculated using the 6 blade gauge signals and the [A] matrix. The 3 blade torsion signals predominated in the calculation of blade spindle torque The similarity of the calculated blade spindle torque to the blade torsion signals can be seen by comparing Figure 4.3.1-6 with Figure 4.3.1-2.

4.3.15 Blade Force

The blade force signal was calculated by multiplying the 6 blade gauge signals by the [A] matrix. The calculated force on the blade was only that component of the force which was perpendicular to a plane passing through the gauge locations of the blade, at the blade pitch equivalent to 0.47 relative radius. The calculated blade force for test number 42 is shown in Figure 4.3.1-6.

4.3.16 Radial Location

The "ANALYZE4_1" program uses the calculated blade force and bending moment quantities to calculate the equivalent radial location of the load for each data point. A plot of the calculated radial location is given in Figure 4.3.1-7. The spikes which can be seen to go off scale were due to the vibration of the blade during the ice/propeller interaction. Since the radial location was calculated by dividing bending moment by the calculated blade force, if these quantities were small, and one quantity varied slightly, the calculated radial location varied greatly. The calculated radial location did not go off scale while the maximum load was applied to the blade.

The radial location shown in Figure 4.3.1-7 is provided relative to the root of the blade at 0.37 relative radius.

4.3.17 Circumferential Location

The circumferential location of the blade load shown in Figure 4.3.1-7, was calculated from the out-of-plane component of the blade force and blade spindle torque quantities. It can be seen that the calculation of the circumferential location suffered the same sensitivity to blade vibration as did the calculation of radial load location. This leads to errors in the calculation of the circumferential location because the spindle torque which results from the in-plane component of the force is not accounted for during the calculation of the circumferential location.

The circumferential location is given relative to the centerline of the blade. Figure 4.3.1-7 shows the location of the out-of-plane blade force to be on the trailing side of the blade centerline during normal propeller operation. This matches the known positive spindle torque (decreasing the pitch) which exists on the blade during normal operation.

4.3.18 Shaft Rate Pulse

The shaft rate pulse shown in Figure 4.3.1-7 occurred once per shaft revolution. The pulse occurred when the center of the instrumented propeller blade was at the 10 o'clock position, looking forward. The actual shaft rate pulses were the +10 volt pulses as seen in Figure 4.3.1-7. The shaft rate pulse occurred more quickly than the scanner was able to reliably capture, and therefore the pulses used to determine the shaft speed were the negative going pulses. These pulses were a result of the inductances and capacitances in the signal lines.

4.3.19 Filtered Calculated Quantities

The "ANALYZE4_1" program also has the capacity to subject any of the signals to a low pass filter to delete unwanted higher frequencies. As an example of the filtering capability, plots of the filtered outputs for the calculated bending moment, spindle torque, force, radial location, and circumferential location as are presented in Figures 4.3.1-8 and 4.3.1-9.

The calculated quantities were subject to a filter with a roll-off frequency of 50Hz. Only the three calculated quantities of blade bending moment, spindle torque and force, were actually filtered. The filtered radial and circumferential locations were actually recalculated using the filtered calculated blade bending moment, spindle torque and force.

Besides filtering the calculated quantities, the "ANALYZE4_1" program can also filter any channel of data and store it in a separate channel set aside for the filtered data.

4.3.20 Shaft Speed

The shaft speed signal shown in Figure 4.3.1-9 was calculated from the shaft rate pulse shown in Figure 4.3.1-7. The reason the shaft speed appears to change in steps, is because the shaft rate pulse was only sensed once per revolution. Therefore the readings shown in

Figure 4.3.1-9 represent the average shaft speed for each revolution.

Figure 4.3.1-9 shows that the mean shaft speed was approximately 209 RPM. This is a good indication that the ship was operating in constant RPM mode, because this was the full speed of the shaft. When the ship was operating in icebreaking mode, the shaft speed was generally less than 200 RPM.

The increase in shaft speed at the 1 second mark was due to the higher than required fuel rack setting (Figure 4.3.1-5), accompanied by a reduction in shaft torque due to the end of the first ice/propeller interaction. The shaft speed decreased at the 1.5 second mark as a result of the ice milling requiring more shaft torque than the engine alone was able to supply. The extra shaft torque was developed from the stored energy of the propulsion system.

After the ice milling event was finished, at approximately 2 seconds, the shaft speed again increased due to the high fuel rack setting and the reduced propeller pitch. The shaft actually experienced overspeed before the engine control system had a chance to reduce the fuel rack setting and increase the pitch sufficiently to load down the system.

4.3.21 Fast Fourier Transform

The "ANALYZE4_1" program also has the capability of performing a Fast Fourier Transform (FFT) on any channel of data. A sample FFT output is shown in Figure 4.3.1-10. The peaks in the FFT show the predominant frequencies at which the propeller blade was vibrating in the "Out-of-Plane Bending" mode. Since the importance of the peaks is proportional to the square of the frequency, the large peaks, at say 1 1/2 Hz, do not indicate important blade frequencies.

4.3.22 Test Statistics

Statistics for each of the 343 tests were produced, as described in Section 4. The statistics for test number 42 are presented in Table 4.3.1-1. The meanings of columns 1, 2 and 3 in Table 4.3.1-1 are given in Section 4.1, (Tables 4.1.-2 and 4.1-3).

Row numbers 25, 26 and 27, in Table 4.3.1-1, list the statistics for the largest thrust event during the test. The lack of data in rows 25, 26 and 27, indicates that the "ANALYZE4_1" program did not find an event in the

DATA FOR EVENT NUMBER : 42

#	CHANNEL	COL 1	COL 2	COL 3	UNITS
1	BLADE CENTRE BENDING	-8.15	149.83	26.99	MPa
2	BLADE TRAILING EDGE TORQUE	-7.18	9	3.79	MPa
3	BLADE LEADING EDGE BENDING	-16.91	133.38	15.16	MPa
4	BLADE CENTRE TORQUE	-17.89	8.86	2.49	MPa
5	BLADE TRAILING EDGE BENDING	-4.38	100.26	24.67	MPa
6	BLADE LEADING EDGE TORQUE	-28.63	9.93	.99	MPa
7	SLIDING BLOCK FORCE	-116.09	191.85	72.87	kN
8	SHAFT THRUST	-631.08	111.96	-213.55	kN
9	SHAFT TORQUE	91.69	230.99	134.26	kN.m
10	SERVO OIL PRESSURE	-31.24	12.48	-10.39	bar
11	LOC. and DIR. OF MAX FORCE	.85	-.01	1	m
12	AFT TOP PROBE	-.43	.55	.16	mm
13	FUEL RACK	21.37	32.94	25.73	mm
14	TYPE OF INTERACTION	2	N/A	N/A	
15	INTER.#, ICE or WATER, DIR.	4	1	1	
16	PROPELLER PITCH	22.36	25.13	23.41	deg
17	SHIP SPEED	5.08	5.39	5.23	m/s
18	RUDDER ANGLE	5.66	43.73	24.1	deg
19	BLADE BENDING MOMENT	-7.64	123.16	22.44	kN.m
20	BLADE SPINDLE TORQUE	-22.4	33.96	14.87	kN.m
21	BLADE FORCE	-63.32	146.76	24.43	kN
22	SHAFT SPEED	200.9	211.2	207.63	rpm
23	BLADE START PEAK & DURATION	183.18	242.99	131.56	deg
24	TQ.ENG.&DUR.;F.AREA;IPI;PWR	763.42	1.31	3.62	
25	THRUST ST. PK. & END TIME	N/A	N/A	N/A	s
26	THRUST ST. PK. & END THRUST	N/A	N/A	N/A	kN
27	THRUST ST. PK. & END TORQUE	N/A	N/A	N/A	kN.m
28	TORQUE ST. PK. & END TIME	1.49	1.76	1.84	s
29	TORQUE ST. PK. & END THRUST	-181.8	-239.4	-297	kN
30	TORQUE ST. PK. & END TORQUE	133.97	230.99	133.27	kN.m

N/A - MEANS 'NO DATA AVAILABLE'

TITLE:
STATISTICS FOR TEST# 42

TABLE No. 4.3.1 - 1

shaft thrust signal conforming to the criterion of a thrust event in the program. For the program to recognize a thrust event, the difference between the maximum and minimum thrust during the test must be greater than 250 kN, and the absolute value of the mean thrust must be greater than 250 kN. For the program to recognize a torque event, the mean torque during the test must be greater than 100 kN*m, and the maximum torque must be 25% larger than the mean torque during the test.

Row numbers 28, 29 and 30, give the statistics for the shaft torque event. The torque event found by the ANALYSE4_1" program was the pulse with the largest measured shaft torque.

4.4 Blade Force Analysis

4.4.1 Hydrodynamic Load

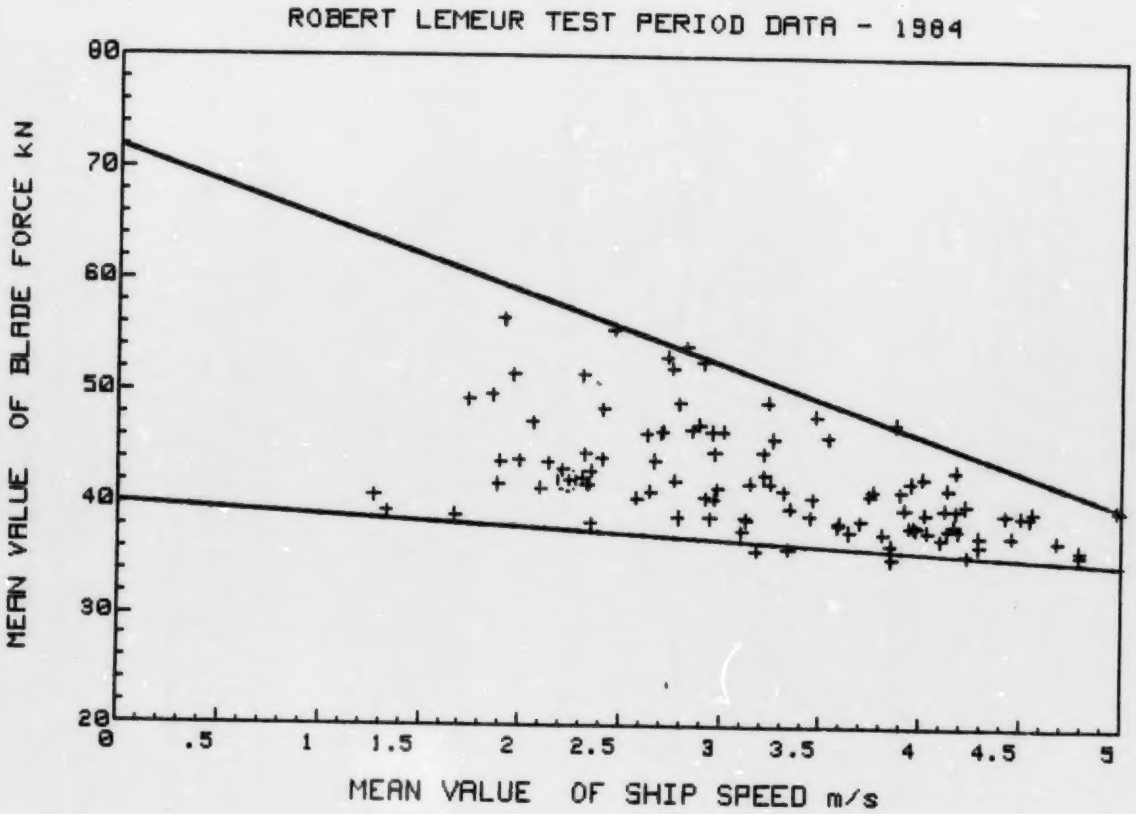
Mean values of the blade force reflect the hydrodynamic steady state (no ice load) load condition, since ice load contribution is negligible during the 7 second event window duration. The value of the blade force induced by the steady state hydrodynamic loads is a function of ships speed. Figure 4.4.1-1 shows this relationship. The best fit line is given by the equation:

$(BF)_{hydro}$ = 51.5 - 2.92 x [ship's speed], where blade force is in kN and ship's speed is in m/s.

The data represents approximately 720 seconds of ice operating time. The large scatter reflects the different operating conditions during which data was collected. It does not represent wake induced fluctuations, since the blade force is averaged over 6.81 seconds (approximately 23 revolutions).

From Figure 4.1.1-1 the bollard condition (ship's speed = 0) blade force is estimated to be 51.5 kN (5 tonnes). This estimate is believed to be on a "low side", for the following reasons:

- The gauges pick up the part of the load corresponding to $r/R \geq 0.47$. The loads due to hydrodynamic forces acting below this location are not accounted for (estimated to be less than 5% of the total load).
- The average measured torque during the trials was 142 kN.m, and the average RPM was 200. This translates into 2970 kW, which is some 10% less then the maximum continuous rated horsepower. The 10%



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 104

DATA SATISFIED THE FOLLOWING TEST(S)

MEAN VALUE OF SHAFT TORQUE > 150 kN.m

CANADIAN
MARINE
DRILLING
LIMITED

MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE: MEAN VALUE OF BLADE FORCE IN FUNCTION OF SHIP'S SPEED

FIGURE No. 4.4.1-1

increase of the blade hydrodynamic load should compensate for the power deficiency.

Note that the strain gauges were calibrated with point loads and not distributed loads. This may lead to inaccurate estimates of the hydrodynamic loads, which are distributed over the whole blade.

Thus the "corrected" hydrodynamic load in open water sailing should be:

- Approximately 6.0 tonnes for the bollard condition.
- Approximately 3.5 tonnes for free running (derived by substituting 7 m/s in the above equation and correcting for power).

Noting that the out-of-plane blade force is directed forward and is inclined to the shaft axis at the pitch angle of 34° (pitch at $r/R = 0.47$), we can translate it to thrust (an approximation only) as:

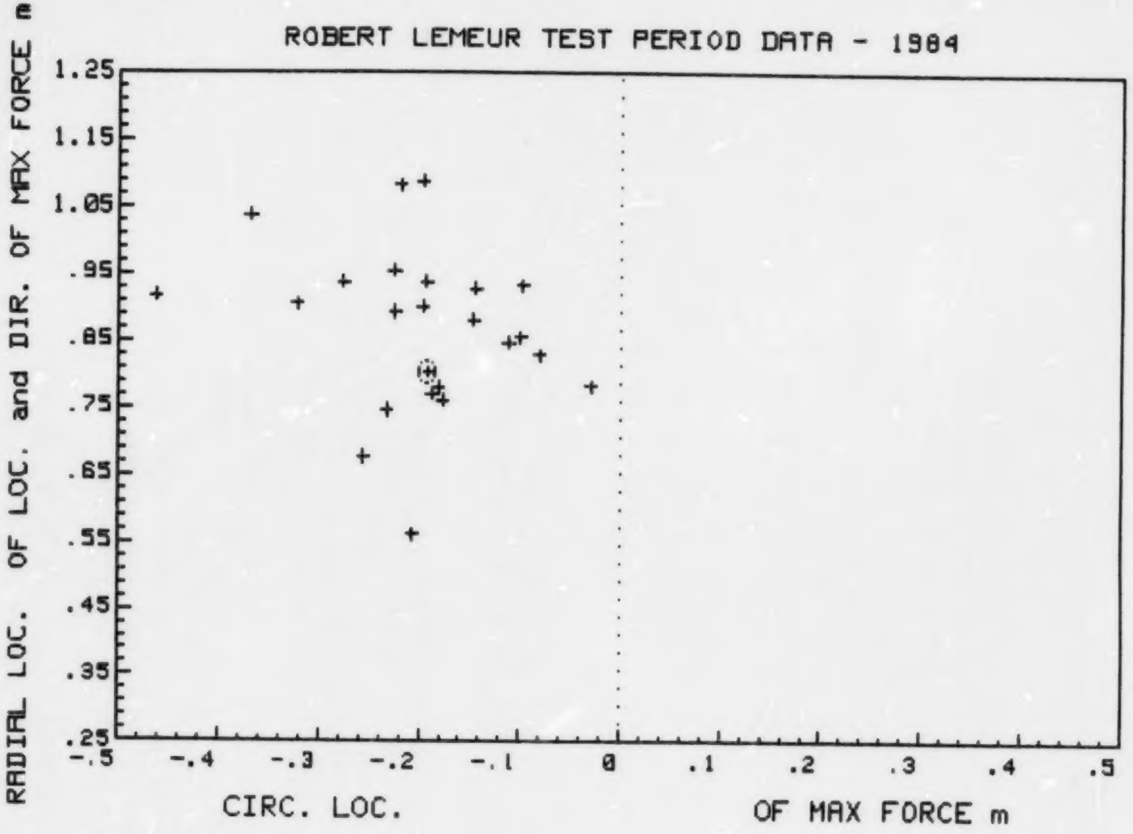
$$\text{Thrust} = 6.0 * \cos 34° = 5.0 \text{ tonnes/blade at bollard condition.}$$

LIPS estimated the propeller thrust at 6.9 tonnes/blade at the bollard.

The calculated values for the location of the hydrodynamic load are shown on Figure 4.4.1-2. From this Figure it can be concluded that:

- The vertical location of the hydrodynamic load is 0.85 m above the blade root, which is at $r/R =$ 0.94 (0.85m + 0.560m for the hub). This estimate seems to be high when compared to LIPS estimate of the location of the hydrodynamic thrust at $r/R =$ 0.7.
- The circumferential location of hydrodynamic load is aft of the centre of the blade (approximately 0.1 m) as expected. However due to the small magnitude of water loads, the scatter of the calculated locations is very high (see chapter 3 in Milestone 1 for the calculation procedure).

Calculated hydrodynamic load in bollard condition on the blade, based on 25 tonnes estimated shaft thrust is:



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 25

NUMBER OF POINTS OUTSIDE PLOTTING AREA IS: 1

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE OF LOC. and DIR. OF MAX FORCE = 1
AND
FIRST TYPE OF TYPE OF INTERACTION = 0

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: LOCATION OF HYDRODYNAMIC BLADE FORCE FIGURE No. 4.4.1-2

$F_{blade} = [(\text{thrust/blade})^2 + (\text{torque/lever/blade})^2]^{1/2}$,
where force lever is 1.04 m (i.e., 0.7 r/R after LIPS):

$$F_{blade} = ((25/4)^2 + (14/(4 * 1.04))^2)^{1/2} = 7.2 \text{ tonnes}$$

For the calculated location of the hydrodynamic load of r/R - 0.94, the same procedure yields F_{blade} = 6.7 tonnes.

This total blade force is inclined at 30° (arc tan [torque/lever / thrust]) to shaft centerline. The Out-of-Plane blade force is therefore:
7.2 x cos (34° - 30°) = 7.18 tonnes. Thus the blade force discrepancy between the observed and calculated values is (7.2 - 6)/(7.2) = 17%.

Blade force fluctuation in the steady state hydrodynamic loading scenario (event number 17) is typically 119%[4], which is a significant fluctuation. This is probably due to the large wake non-uniformity, caused by the ship's ice island (which is above the nozzles) and the appendages.

4.4.2 Ice Induced Blade Forces

The distribution of the blade forces during the interactions with ice is given in Figure 4.4.2-1. The following observations can be made:

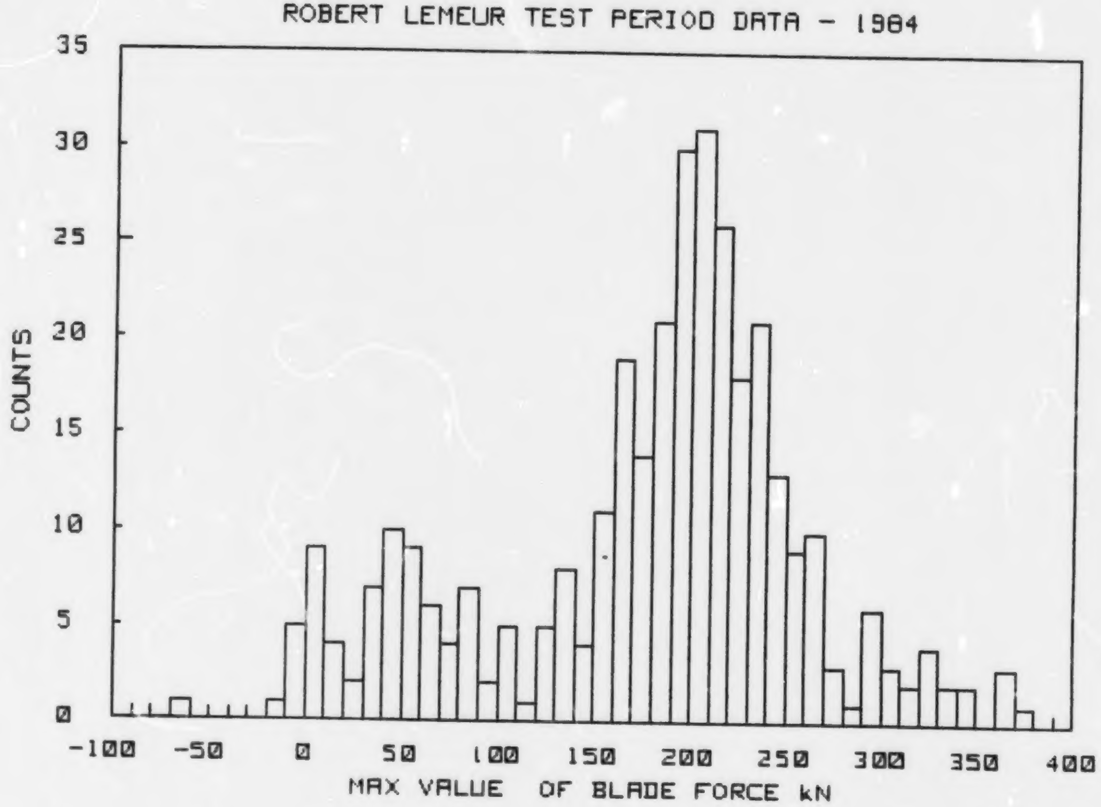
- There are two distinct groups of data: one, centered about the hydrodynamic value of blade force of 50 kN and the other centered about the average ice induced load of 210 kN. This is due to the two types of data sets which are "events" or "open-water" manual scans.
- The maximum recorded blade force was 375 kN, which is 5.3 times higher than the maximum bollard blade force.

A brief description of the largest blade force event (No. 72) is as follows:

The ship was moving at 3.7 m/s, with the fuel rack near maximum, shaft RPM was 207.8 and the pitch was set at 19.6° (at r/R = 0.7). There was some small interaction

---

[4] (Max-Min)/Mean



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 340
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:177.37
AND ITS STANDARD DEVIATION IS:82.413

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **STATISTICS OF THE MAXIMUM VALUE OF BLADE FORCE**
		FIGURE No. 4.4.2-1

taking place before the large impact occurred. This is clearly visible on Figure 4.4.2-2. Examination of the records of that event shows that the shaft torque went up significantly indicating that some milling was taking place with the non-instrumented blades. Thrust increased significantly which indicated that the ice impact force was predominantly in the out-of-plane direction. The instrumented blade received one single impact from the ice at the time of 2.4 sec.

The net ice force of 375 kN - 30 kN (mean hydrodynamic force during that event) = 345 kN acting in the Out-of-Plane direction compares well with the derived value of 340 kN from the single impact model force with ice crushing pressure of 20 MPa (Section 7.5 of Milestone 1). The duration of the impact was 0.05 sec.

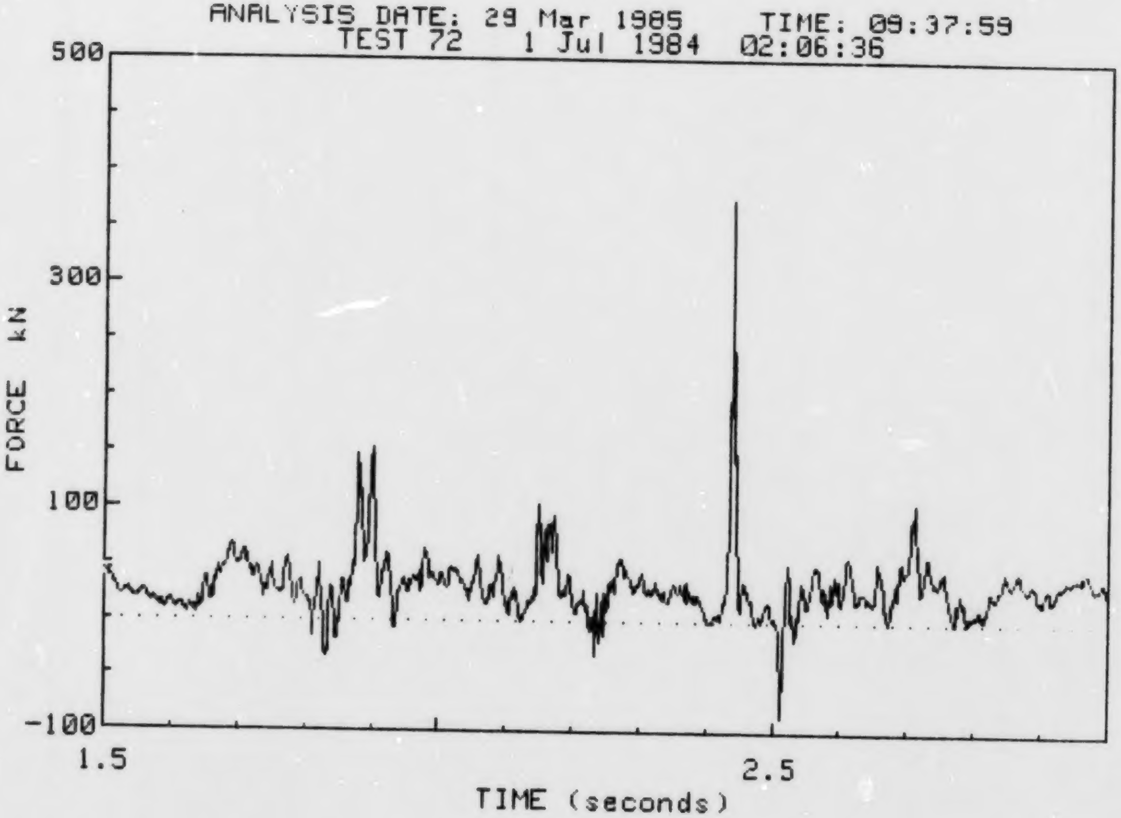
The duration of blade force impact for this event was established as follows: The largest excursion of the blade force from the mean blade force during the 6.81 sec. "window" was first determined. The computer program then stepped back towards the start of the data until a value was found which was on the opposite side of the mean value (essentially equal to the mean value). The time of this point was the start of the event. The program then started at the maximum excursion of the force, and stepped forward though the data points until a value was found which was essentially equal to the mean value. The difference in time between the first and last point equals the event duration. The blade force event durations stored in the "statistics" were determined manually using different criteria.

Due to the model's simplifying assumption of hitting the block of ice at right angles to the propeller edge, the predicted force acted predominantly in-plane. A change of the orientation of the ice block edge against the impacting blade would lead to the change of the orientation of the impact force.

Figure 4.4.2-3 shows the dependance of the maximum blade force on the type of interaction.

Important observations can be made after examination of the Figure 4.4.2-3:

- The maximum values of water induced blade forces arising during the blockage events (type 3 interactions) are of the same order of magnitude as the maximum ice-induced force, which occured during the single impact event (85% of the maximum measured blade

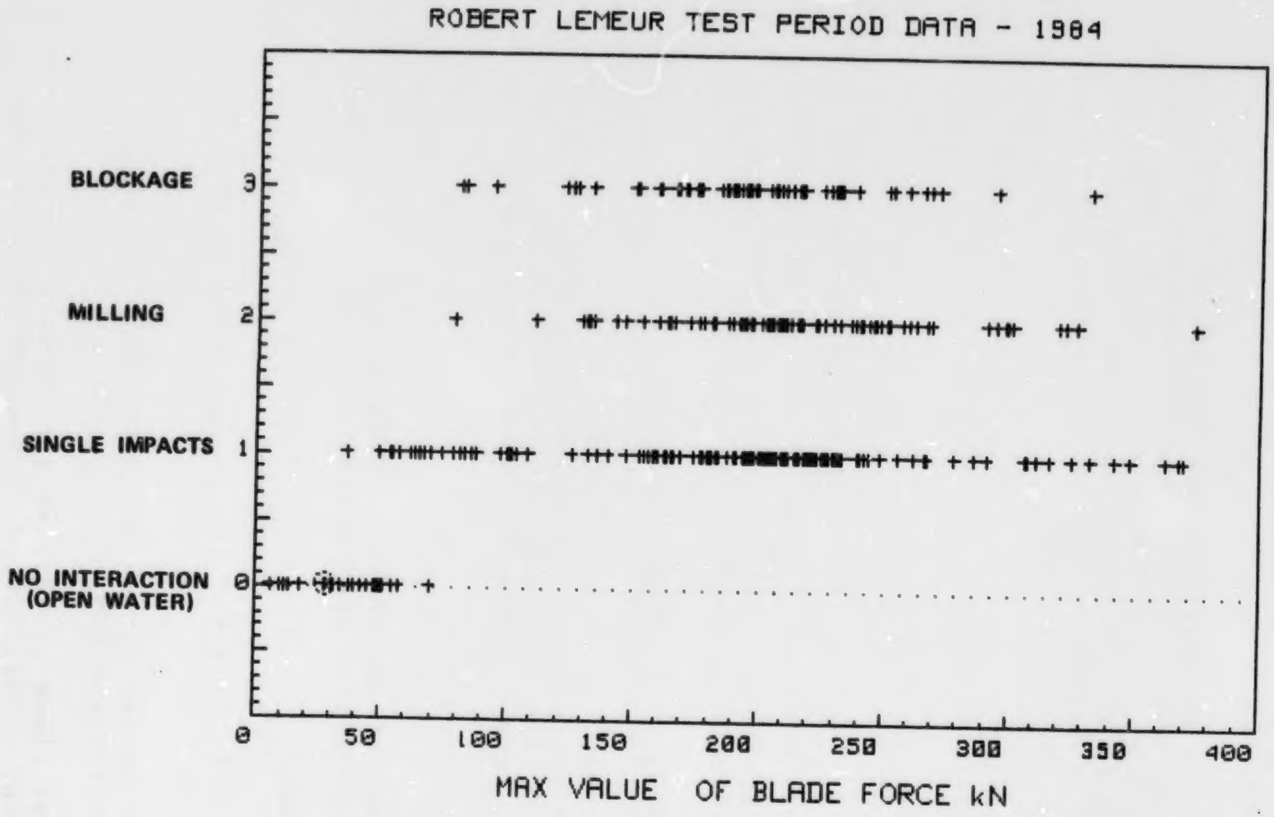


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **TIME HISTORY OF THE BLADE FORCE IN EVENT #72**

FIGURE No. 4.4.2-2



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 321

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE OF LOC. and DIR. OF MAX FORCE > 0

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: DEPENDANCE OF THE MAXIMUM FORCE ON THE TYPE OF INTERACTION**
		FIGURE No. 4.4.2-3

force). This suggests that the water may be an important component in every type of interaction. At this moment however, it is impossible to distinguish which part of the ice impact load is due to the ice and which is due to unsteady water flow.

- The mean value, as well as the maximum value of the maximum blade force does not change appreciably with the change in the type of interaction.

Blade forces, as measured, are the out of plane components of the total blade force. Consequently, blade strain gauges cannot supply adequate information about the direction of the force acting on the blade. Such information can be extracted however from the shaft torque and shaft thrust data as follows:

An instantaneous thrust during an ice event can be thought to be composed of:

$$T = \Delta T_{ice} + 4T_{ow}$$

where ΔT_{ice} is the thrust increment on one blade due to ice interaction and T_{ow} is the thrust of the blade in open water condition. Similarily an instantaneous torque can be thought to be composed of:

$$Q = \Delta Q_{ice} + 4Q_{ow}$$

Assuming that the radial location of the blade force does not change appreciably during the ice interaction (it remains at 1.1 m from the shaft centerline) we can transform the torque into the force causing torque:

$$\Delta F_Q = \Delta Q/1.1 \text{ m}$$

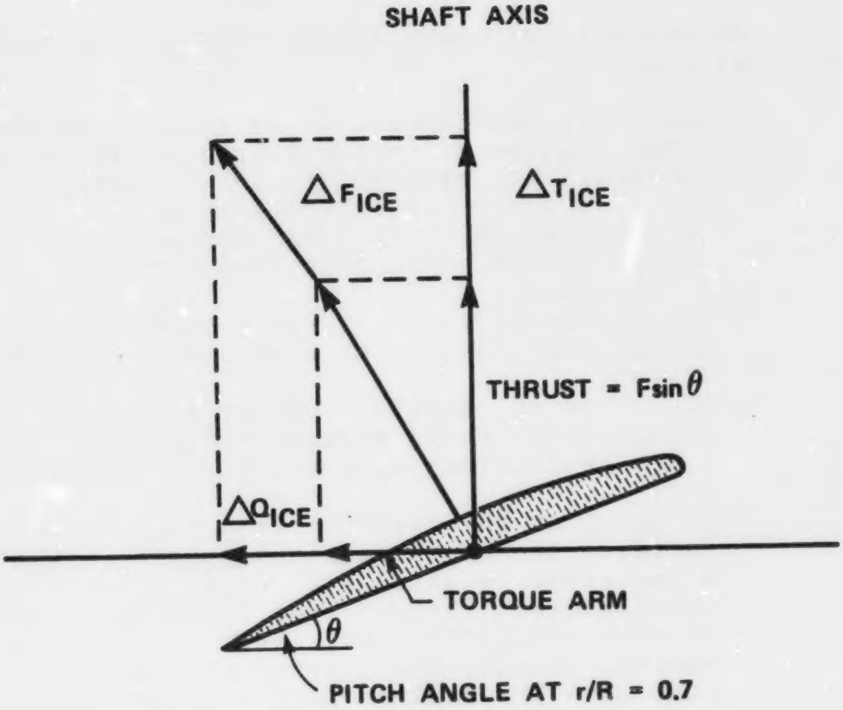
The tangent of the angle between the ice force vector and the propeller disk plane can be calculated as:

$$\tan \alpha = \Delta T_{ice}/\Delta F_{Qice} = (T - 4T_{ow}) * 1.1/(Q - 4Q_{ow})$$

See Figure 4.4.2-4 for the illustration of this relationship.

The above quoted method has many imperfections. Among the imperfections are:

- Response times of torques and thrusts are vastly different. Readings of torque and thrust at any


SHAFT AXIS
ΔF_{ICE}
ΔT_{ICE}
THRUST = $F\sin\theta$
ΔQ_{ICE}
TORQUE ARM
θ
PITCH ANGLE AT r/R = 0.7

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: GEOMETRY OF ICE FORCE/ INCREMENTAL ICE LOAD FIGURE No. 4.4.2-4

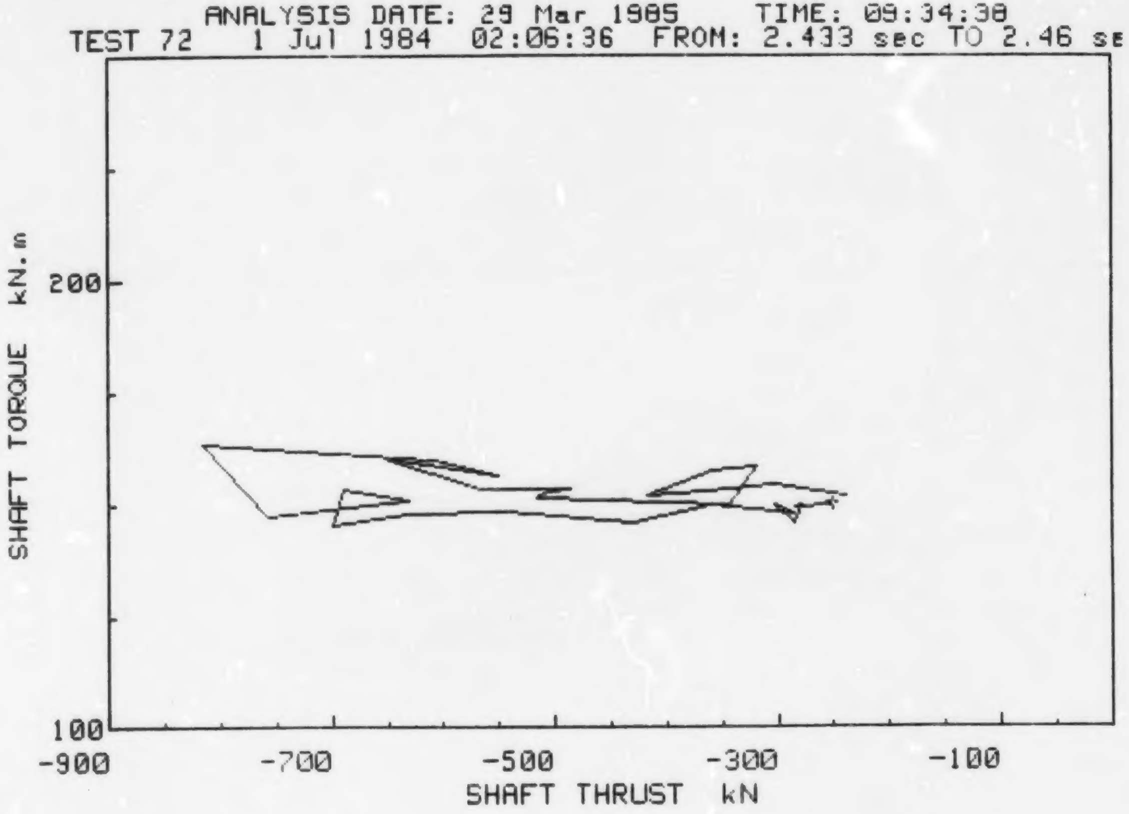
particular time instance are not necessarily the readings of the same input function.
- Calculated locations of the force vectors are subject to large error.

Therefore only qualitative assessment of the direction of force application is possible at this time.

To do this assessment, a group of torque versus thrust plots were created in which torques and thrusts were correlated among themselves. Figures 4.4.2-5 and 4.4.2-6 illustrate these correlations.

An analysis of these events lead to the following observations:

- There are two categories of thrust "events" namely those leading to thrust increase and those leading to thrust decrease during the "events". To the later category belong the events:
  84, 85, 86, 109, 150, 173, 194 and 202. Those events are of very short duration (few milliseconds).
- During these "events", the torque does not vary appreciably due to the high inertia of the torque system.
- Above listed "events" testify about the direction of the force being predominantly axial (along the shaft centerline) with the force vector directed aft.
- Majority of the "events" lead to the thrust increase (force vector is directed forward).
- A number of "events" are "pure torque" "events" which suggest that the ice force was directed in-plane ("events" 149, 150).
- Maximum thrusts are reached at the times other than when the maximum torque is measured due to the difference in the inertias of torque and thrust systems. Therefore the maximum stresses in the shafts due to maximum torque and maximum thrust do not have to be added.
- Some "events" (No. 154 for example) show a decrease of torque along with an increase of thrust. This cannot be explained satisfactorily at present.

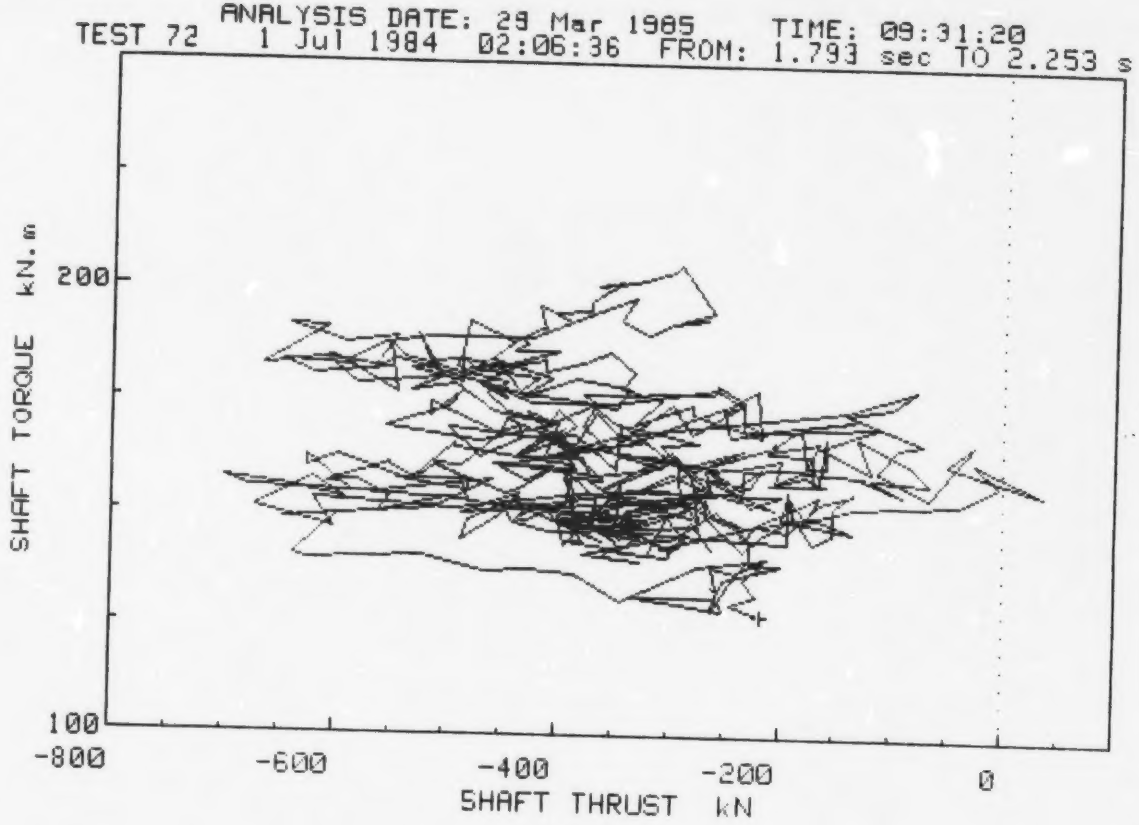


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: SHAFT THRUST/TORQUE DISTRIBUTION DURING THRUST EVENT

FIGURE No. 4.4.2-5



CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: SHAFT THRUST/TORQUE DISTRIBUTION DURING TORQUE EVENT

FIGURE No. 4.4.2-6

Radial and circumferential locations of the ice induced forces are plotted on Fig 4.4.2-7. This plot, when compared with the pure open water condition plot (Fig 4.4.1-2) shows the following:

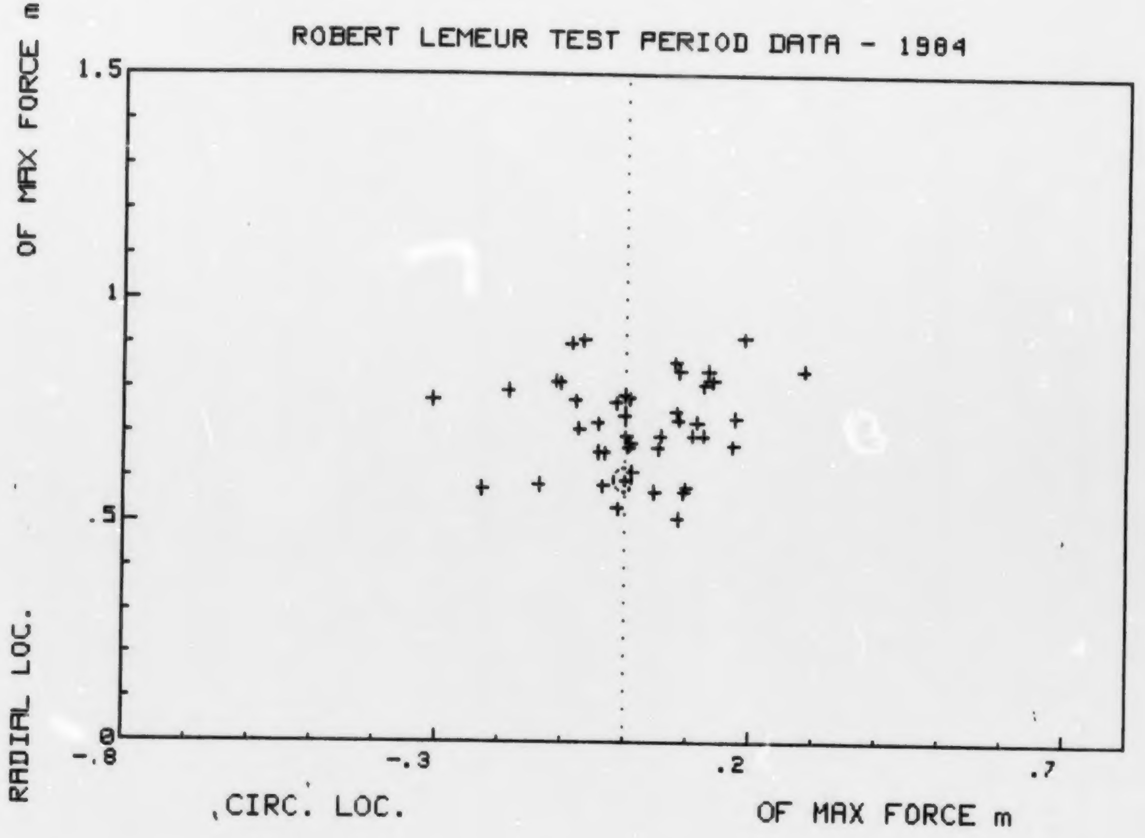
- Circumferential location of the ice force is near the centre of the blade, but some distance forward of the hydrodynamic load location.
- Radial location of the high impact force (including the hydrodynamic component) is calculated at about 0.7 m above the blade root (r/R = 0.84). These locations are lower than the locations of hydrodynamic load (r/R = 0.94). This can be explained by the examination of the hydrodynamic load distribution on the blade, as presented by LIPS (see Figure 4.4.2-13).

Figures 4.4.2-8, 4.4.2-9 and 4.4.2-10 show the locations of blade forces for the different types of interactions. They show that the locations (both radial and circumferential) do not depend significantly on the type of interaction.

Figure 4.4.2-11 shows the points of application of the blade force in the astern pitch condition. The points of application of forces are shifted significantly towards the leading edge of the blade and their radial location is approximately at 0.77 r/R.

Figure 4.4.2-12 shows the dependance of the maximum blade force on the radial location. The following observations can be made:

- Highest force occurred at low radius r/R = 0.69 (1.04 m above the shaft centerline).
- Highest blade forces occurred at the radial location of 0.50 m to 0.85 m above the blade root (0.6 < r/R < 0.86).
- There is a strong tendency of the blade force decreasing with increasing radial location of the force.
- The average radial location is at approximately .85 m above the root (r/R = 0.86).
- For the impacts located near the tip of the blade, the algorithm calculating the force location (["A"] matrix) is exaggerating the radial location points.
- Low radial locations (0.75 < r/R), are always associated with high impact forces. High impact forces at low radial locations can be explained by noting that both the pitch angle and the blade thickness at the leading edge grow with

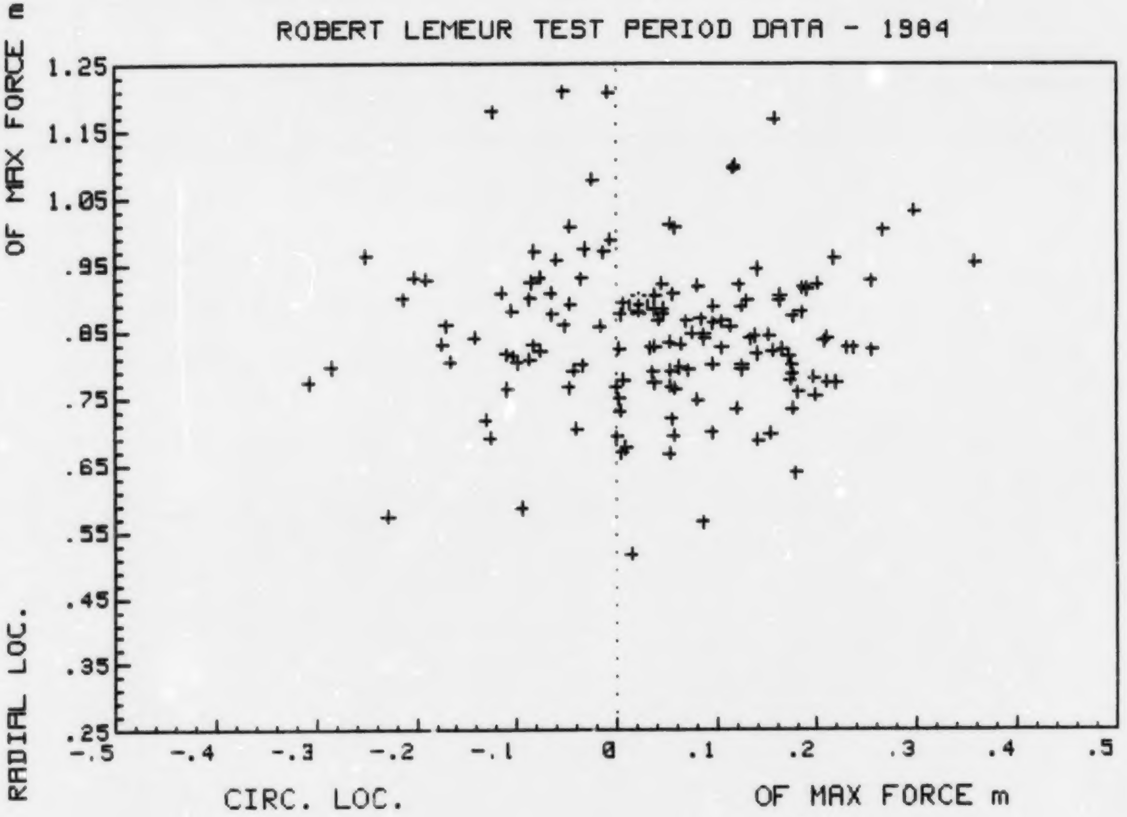


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 44

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE OF LOC. and DIR. OF MAX FORCE = 1
AND
MAX VALUE OF BLADE FORCE > 250 kN

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: CIRCUMFERENTIAL & RADIAL LOCATIONS OF MAXIMUM FORCE
		FIGURE No. 4.4.2-7



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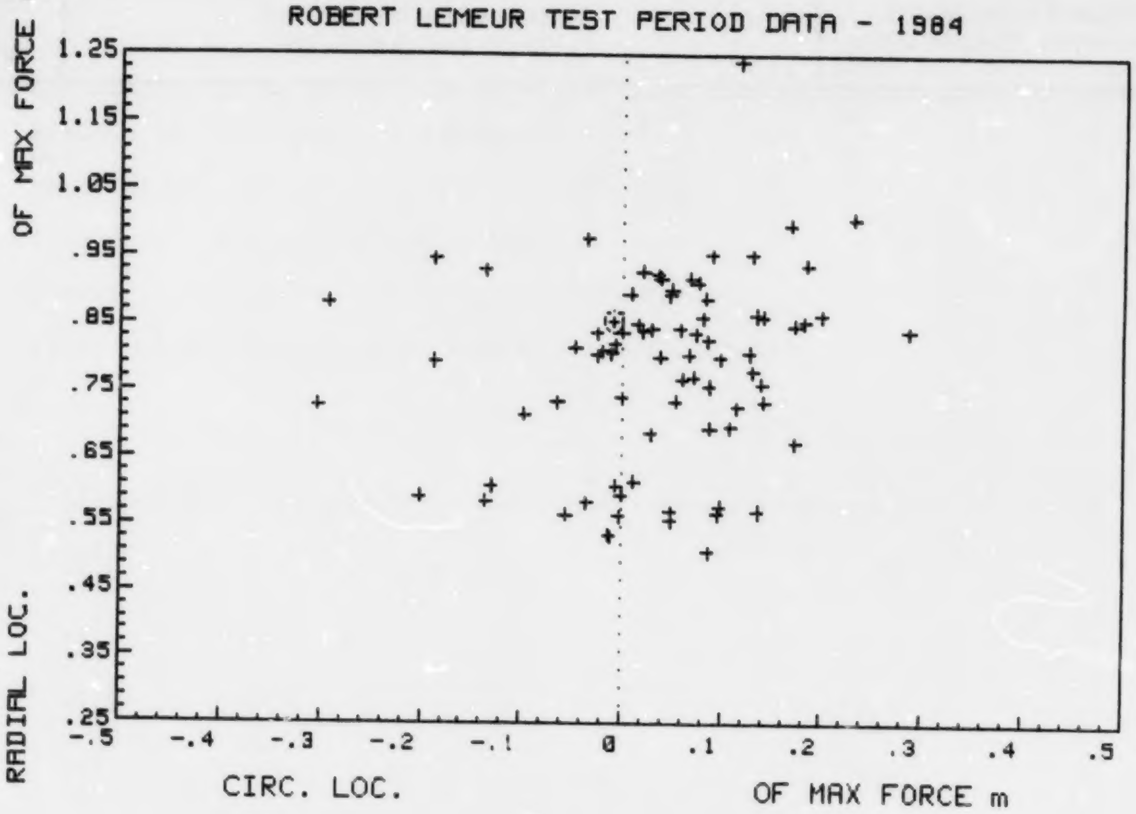
TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 145

NUMBER OF POINTS OUTSIDE PLOTTING AREA IS: 2

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE  OF LOC. and DIR. OF MAX FORCE = 1
AND
FIRST TYPE  OF TYPE OF INTERACTION = 1
```

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: CIRCUMFERENTIAL & RADIAL LOCATION OF THE MAXIMUM FORCE DURING SINGLE IMPACT**
		FIGURE No. 4.4.2-8



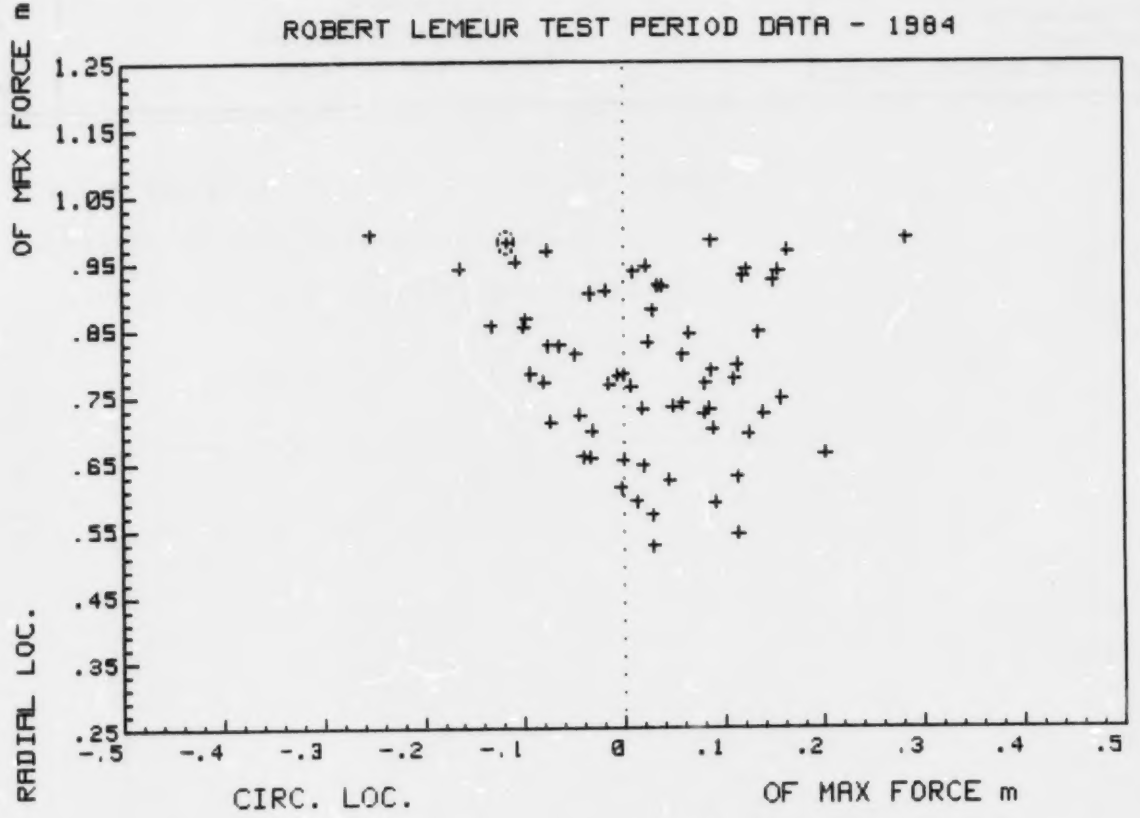
TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 78

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE OF LOC. and DIR. OF MAX FORCE = 1
AND
FIRST TYPE OF TYPE OF INTERACTION = 2

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: CIRCUMFERENTIAL & RADIAL LOCATIONS OF MAXIMUM FORCE FOR MILLING EVENTS
		FIGURE No. 4.4.2-9

ROBERT LEMEUR TEST PERIOD DATA - 1984

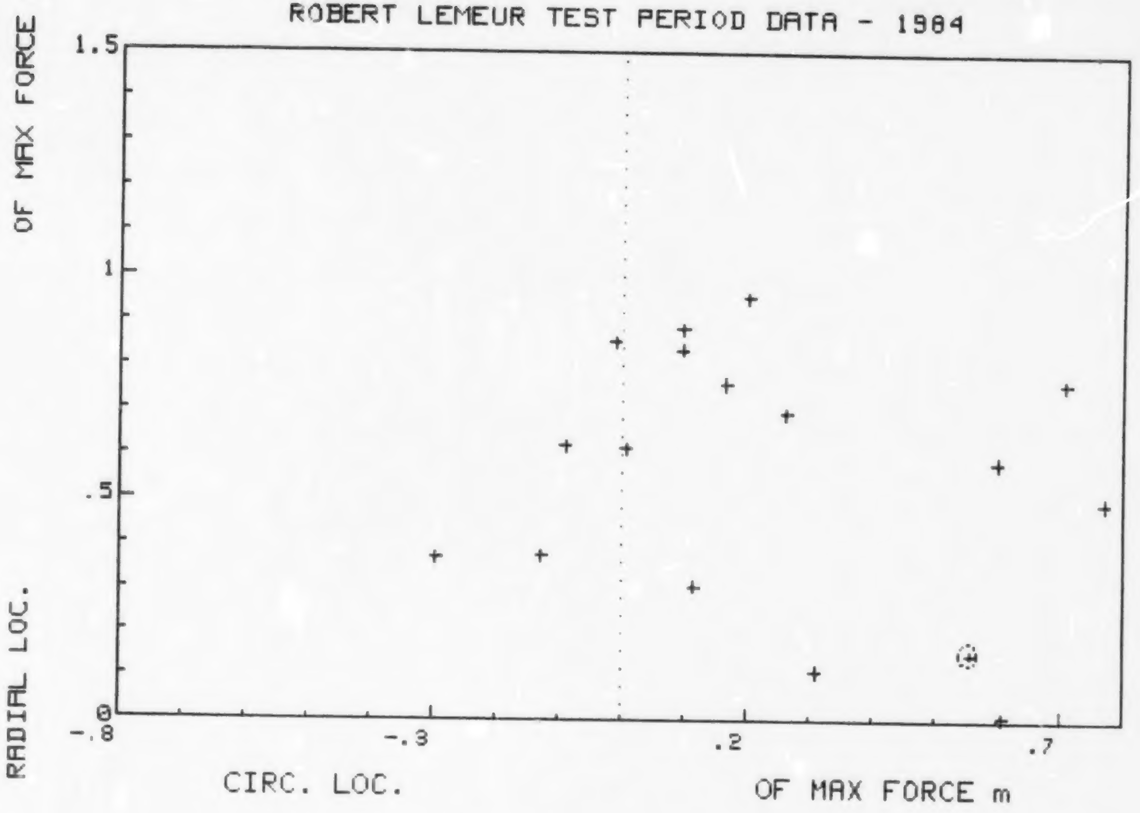


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 64

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE OF LOC. and DIR. OF MAX FORCE = 1
AND
FIRST TYPE OF TYPE OF INTERACTION = 3

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: CIRCUMFERENTIAL & RADIAL LOCATION OF THE MAXIMUM FORCE DURING BLOCKAGE EVENTS FIGURE No. 4.4.2-10



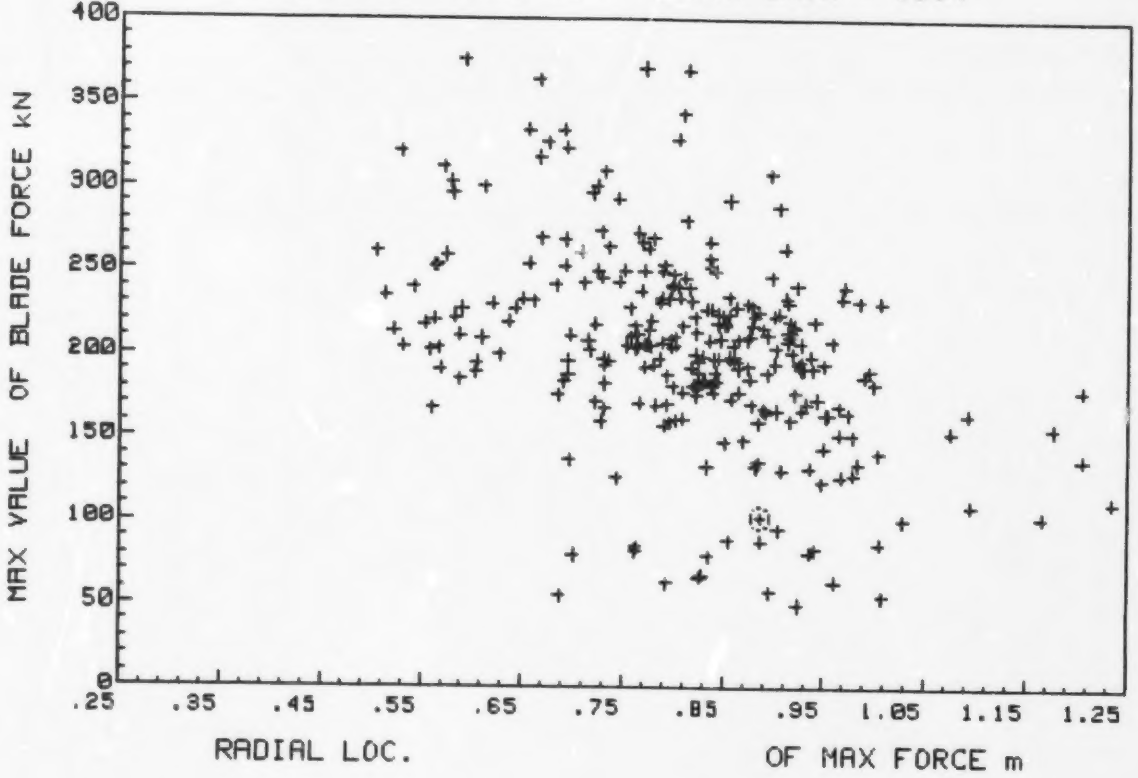
```
TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 17

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE  OF LOC. and DIR. OF MAX FORCE = -1
```

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: CIRCUMFERENTIAL & RADIAL LOCATION OF MAXIMUM FORCE FOR BLADE FORCES DIRECTED AFT.** **FIGURE No. 4.4.2-11**

ROBERT LEMEUR TEST PERIOD DATA - 1984



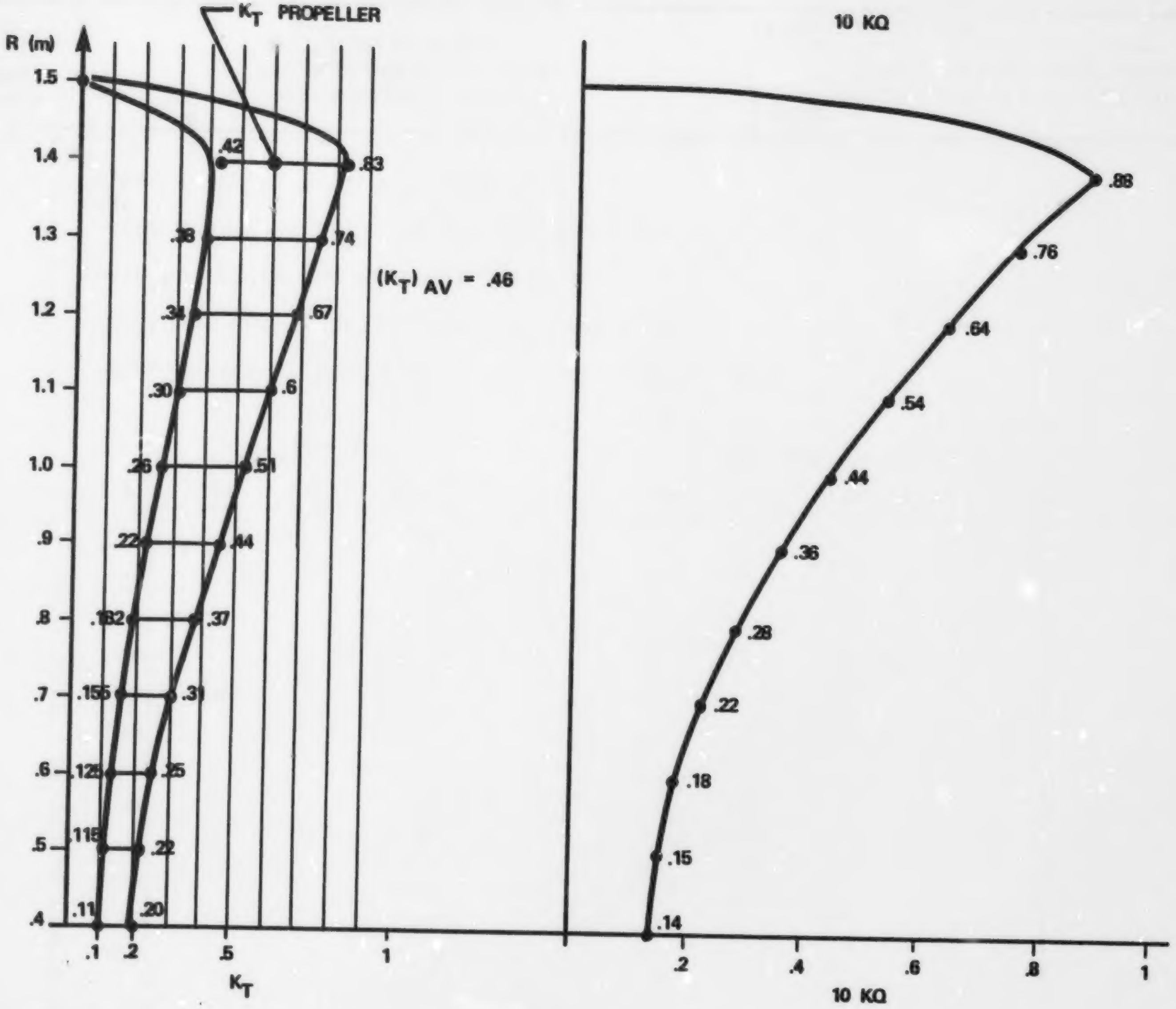
TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 287

NUMBER OF POINTS OUTSIDE PLOTTING AREA IS: 2

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE OF LOC. and DIR. OF MAX FORCE = 1
AND
FIRST TYPE OF TYPE OF INTERACTION > 0

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: DEPENDANCE OF RADIAL LOCATION OF THE FORCE ON THE FORCE MAGNITUDE
		FIGURE No. 4.4.2-12



CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: HYDRODYNAMIC LOAD DISTRIBUTION ALONG THE BLADE
		FIGURE No. 4.4.2 - 13

- the decrease of r/R. Velocity of impact drops, however. This proves that the pitch and thickness of the blade may be contributing more to the ice force than the impact velocity. This effect, combined with the geometrical constraint of ice block size when hitting the blade tip or root lead us to the conclusion that the maximum blade impact forces are developed near the middle of the blade.

However, the data on the circumferential locations of application of the load is suspect. It is not understood how an ice block can create a significant impact in the middle of the blade without first impacting the blade leading edge. One possible explanation is that if the impact is in-plane then the only signals the strain gauges are picking up are due to hydrodynamic loading, which was proven elsewhere to be of a magnitude comparable to ice loads (see description of blockage events).

Another plausible explanation is that the circumferential location is calculated based on the out-of-plane component of ice force only. The other (in-plane) component produces a spindle torque counteracting the one produced by the out-of-plane component. Resultant spindle torque is small, and consequently, the calculated value of the circumferential location is small. If the in-plane component is taken into account in these calculations, the resultant circumferential location of the out-of-plane force would move towards the leading edge. The magnitude of the in-plane force will be determined from the shaft torque signal.

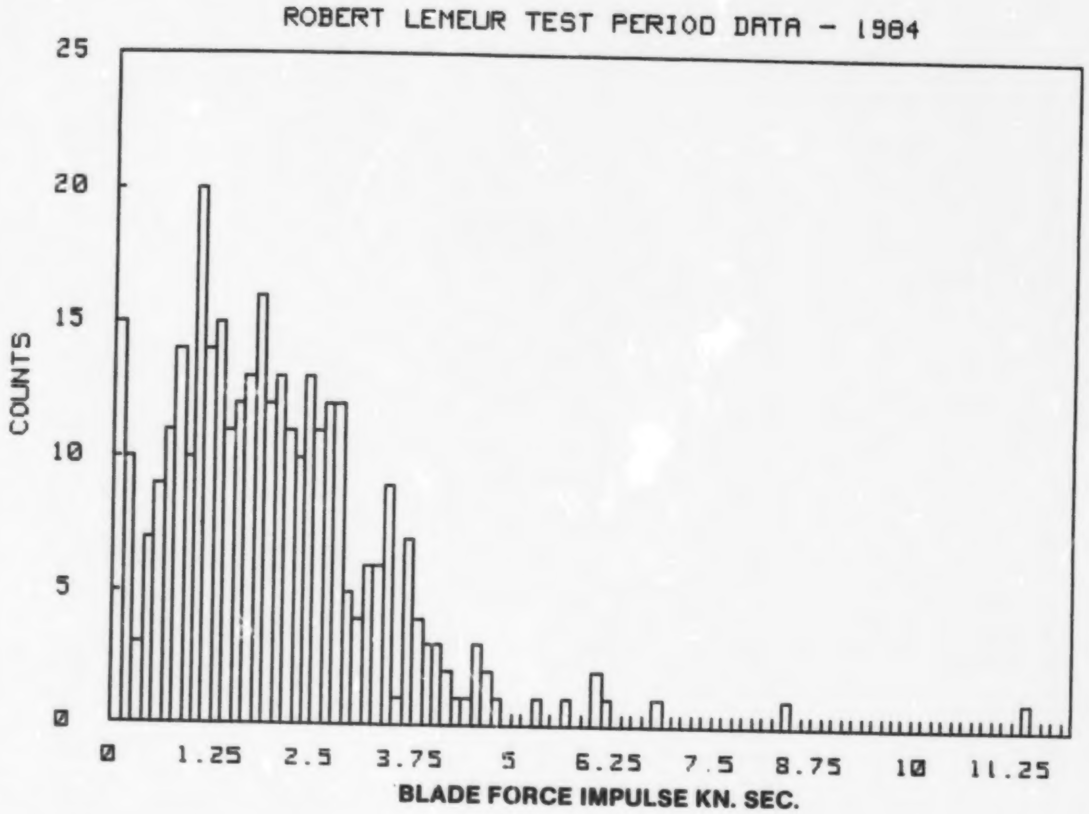
The calibrations performed on the blade produced good results for the location of the load, as presented in Section 3 of Milestone 1. This is due to the small in-plane component during all of the calibration tests.

4.4.3 Impulse Analysis

Figure 4.4.3-1 shows the statistics of the blade force impulse. Impulse is defined as Fdt, where F is the blade force and dt is the duration of the single largest blade force signal peak (above average level of blade force).

The maximum impulse recorded was 11.2 kN * s and the average was 2.0 kN*s.

Plots of various levels of impulses are shown on the figure 4.4.3-5. This plot can be used in estimating the



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 340
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:1.9751
AND ITS STANDARD DEVIATION IS:1.3738

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: STATISTICS OF BLADE FORCE IMPULSE FIGURE No. 4.4.3-1

size of the ice blocks interacting with the propeller. The maximum bending moment event (event number 336) had a very small impulse, and consequently the size of the ice block must have been a very small one.

The data on this event impulse was:

t_1 = 0.2378 sec
t_2 = 0.2391 sec
dt = 0.0013 sec

$F_{max} - F_{hydro}$ = 273 kN, triangular shape impulse.

To estimate the incremental velocity (dV), the following calculations are performed:

The location of the force was 0.8 m above the blade root, which translates into r/R = 0.9. The L.E. (leading edge) velocity at that point was:

$0.9 * 1.5 * 209 * 2\pi = 29.5$ m/s

The normal velocity of the P.S. (pressure side) of the blade was 29.5 m/s * sin 22.4° = 11.2 m/s

Using the fundamental relationship Fdt = mdV, and substituting for dV, F and dt, the calculated minimum mass of the ice block could have been approximately 30 kg.

Figure 4.4.3-2 shows the correlation of the maximum net (maximum - mean)[6] blade force with the force impulse. The following observations can be made:

- Highest blade force values are associated with the short impulses (Fdt < 2 kN * sec), which suggests that these impulses were from single impact events.
- All of the blade events had durations of 0.010 sec or longer. Such a duration corresponds to 0.010 * 11.2 m/s = 0.112 m travel of the impulse force in the direction of the normal to the blade pressure side.
- The work done by the ice excitation force can be calculated as:
  L = (1/2)(F * s) = 0.02 MJ, where s is the distance travelled calculated above.

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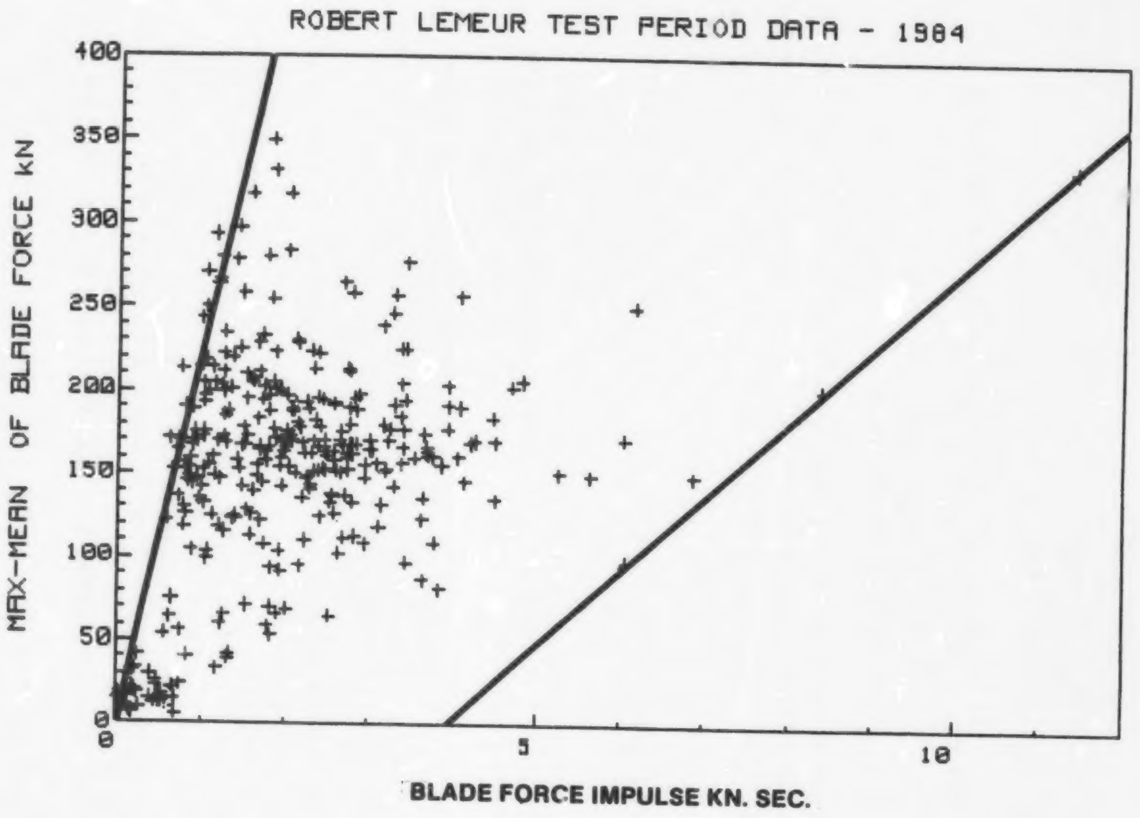
[6] Maximum - mean blade force denotes ice-induced force without mean-level hydrodynamic component.



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 321

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE OF LOC. and DIR. OF MAX FORCE = 1 „

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **DEPENDANCE OF THE IMPULSE ON THE MAGNITUDE OF ICE-INDUCED FORCE**

FIGURE No. 4.4.3-2

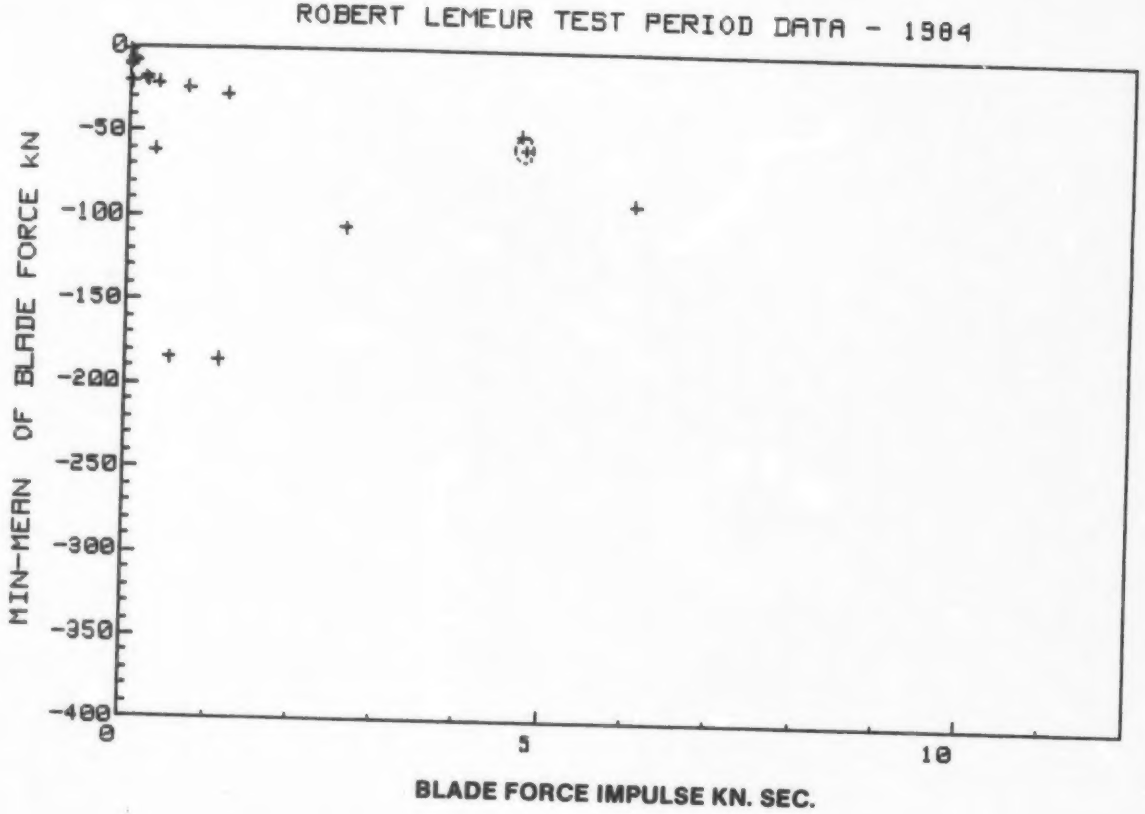
- The events forming the right hand boundary of the data set (highest impulses) were all recorded during the passage through McKinley Channel that is through the refrozen first year ice. The estimated thickness of the first year ice was 1.2m and the average block size was approximately: 1.2 * 0.5 * 0.5 = $0.3m^3$ with corresponding mass of 270 kg, which is near the average size as measured by ice observers (see Milestone 1 Section 6). Channel ice however was harder than the ice encountered during later tests.
- It is conceivable that the large size level ice pieces were supported on the nozzle's surface and did not travel through the nozzle "at once". The largest ice block that can go through nozzle is of approximately $1m^2$, represents the effective mass of 2.4 tonnes. This translates into normal to the blade velocity increment (dV) of less than 5 m/s., which is the reasonable number for acceleration by the p.s. (pressure side) of the blade.
- From Figure 4.4.3-3 we can conclude that the maximum impulse in the astern mode was approximately 1/2 of the maximum impulse in the ahead mode. Again, the maximum impulse was not associated with the maximum load.
- The largest impulse is documented on Figure 4.4.3-4. It is clear that the blade was gradually "digging-in" to the block, as the largest force was generated on the fifth pass of the instrumented blade. This pass was also associated with a sharp increase in the shaft torque (see the documentation of event number 8) which shows that the total ice force had a large circumferential component. This component could have displaced the calculated circumferential position of the out-of-plane force.

4.4.4 Conclusions

- Magnitudes:

  i. The total maximum out-of-plane blade force recorded was 375 kN, which, after subtracting the steady state hydrodynamic load of 30 kN, gives 345 kN of ice induced load.

  ii. This load is 5.3 times higher than the calculated steady state maximum hydrodynamic load in bollard condition.

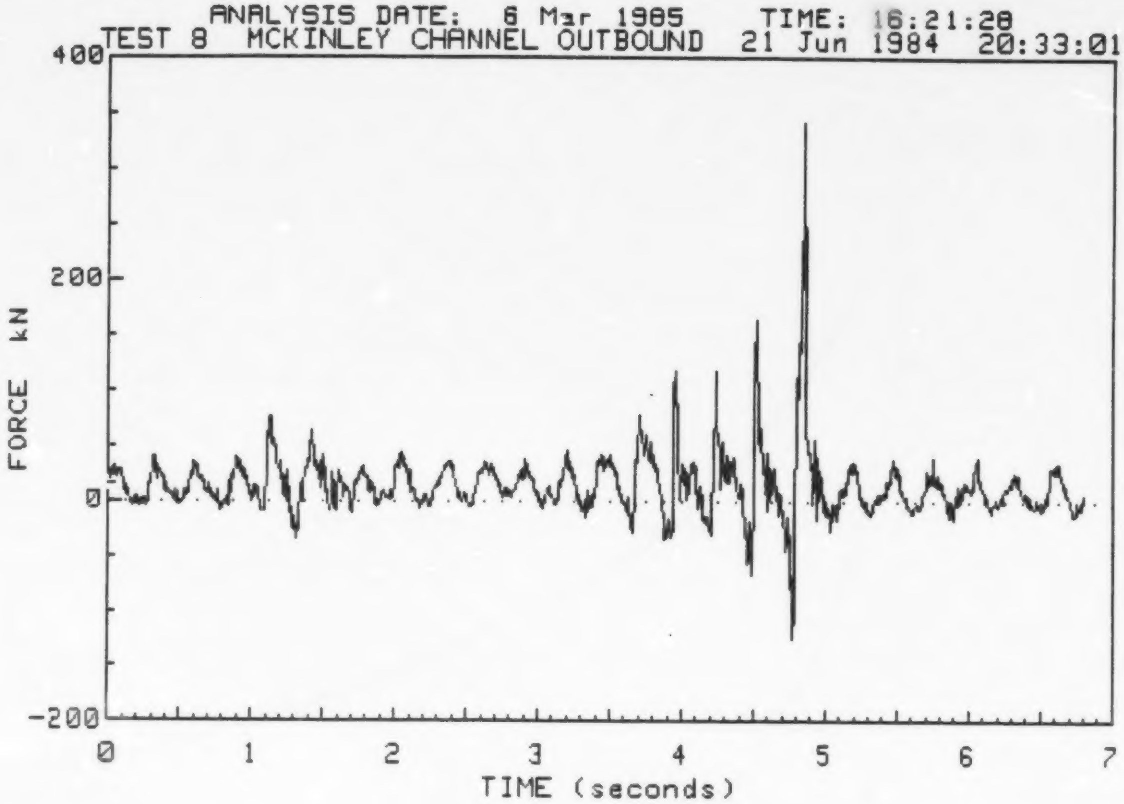


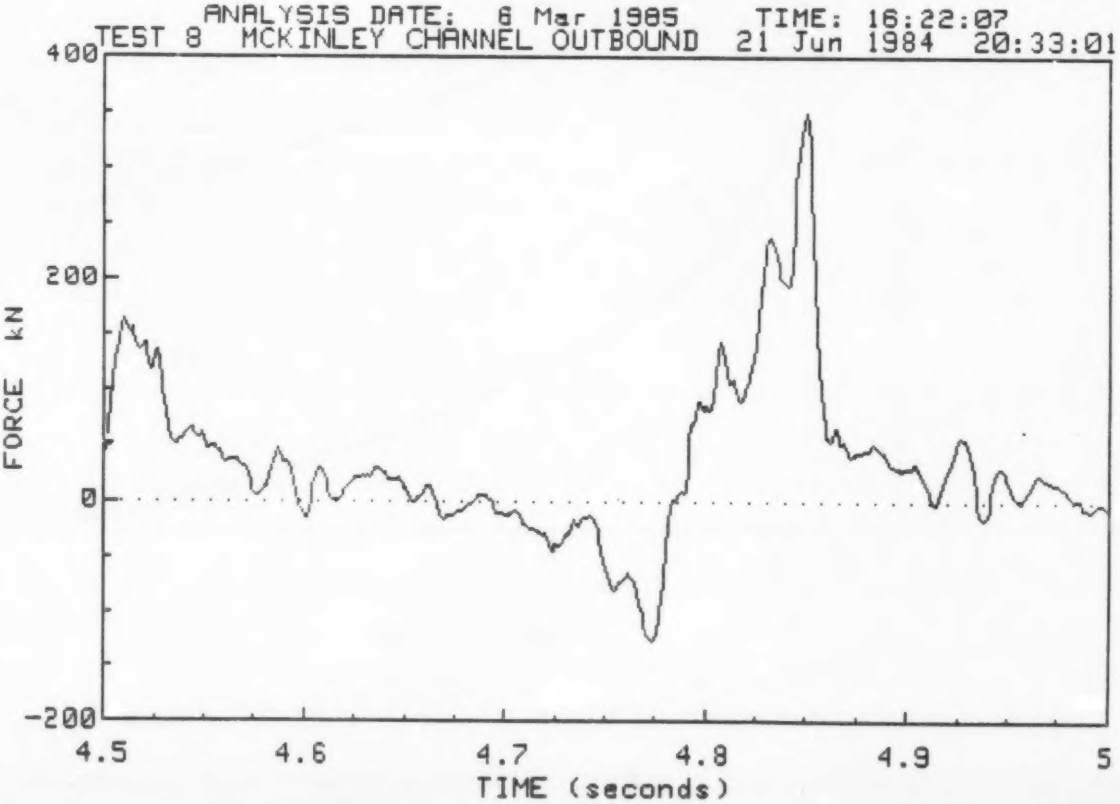
TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 19

DATA SATISFIED THE FOLLOWING TEST(S)

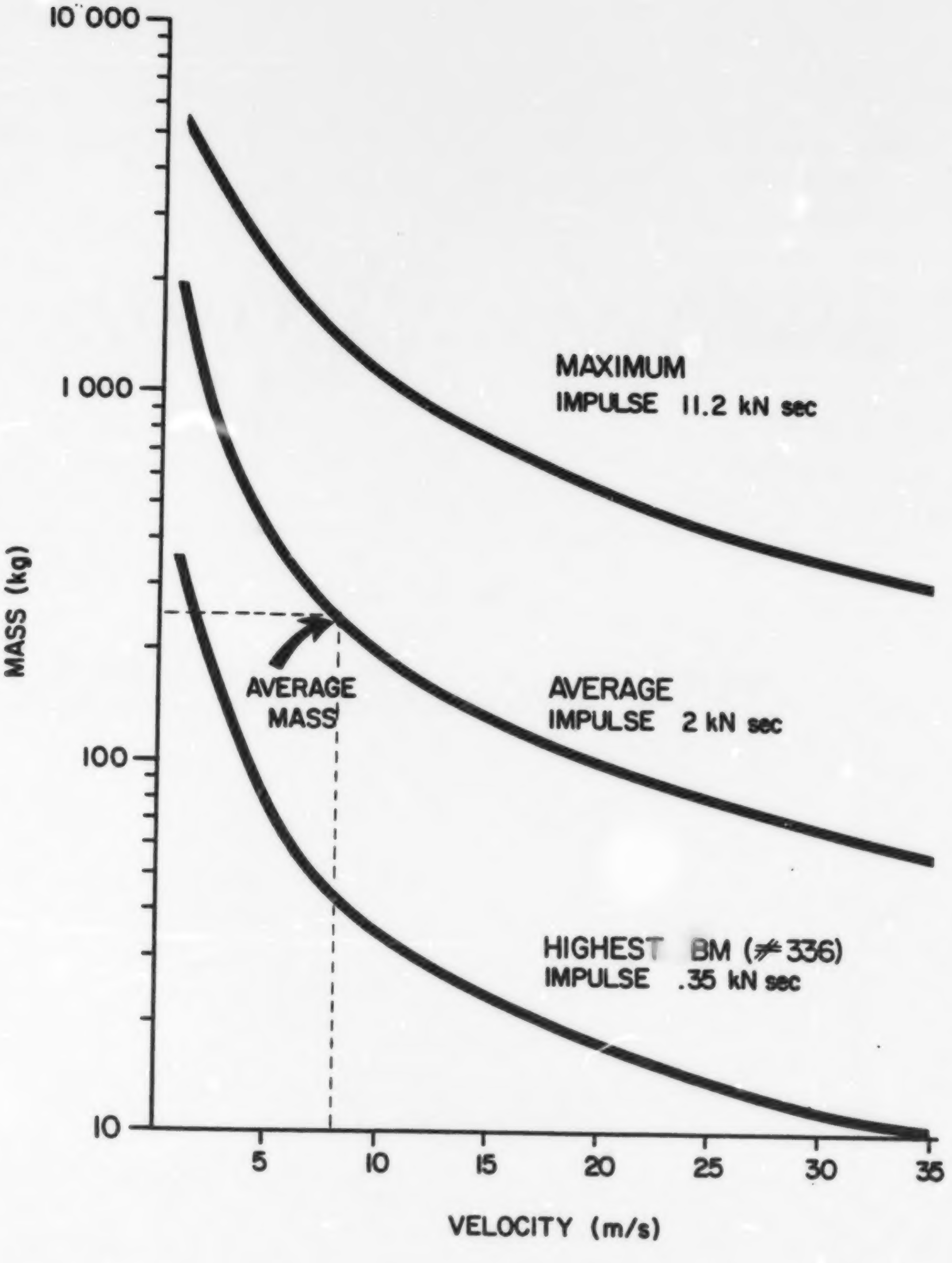
FORCE SENSE OF LOC. and DIR. OF MAX FORCE < 0

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: DEPENDANCE OF IMPULSE ON THE MAGNITUDE OF ICE-INDUCED FORCE FOR THE FORCE DIRECTED AFT. FIGURE No. 4.4.3-3





CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **HISTORY OF MAXIMUM IMPULSE**
		FIGURE No. 4.4.3-4



CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
BLADE IMPULSE CHARACTERIZATION

FIGURE No. 4.4.3-5

iii. Water induced loads in blockage events are of nearly the same magnitude as the highest ice impact loads (85% of the maximum ice impact force).

iv. Considering the above, it is concluded that the water induced loads on the blade during its interaction with ice are a very significant component of the total load.

- Directions

i. Blade forces as measured are inclined 34° (pitch angle at $r/R = 0.47$) to the vertical plane passing through the shaft centerline.

ii. Most of the impact forces were directed forward, however a number of events recorded forces directed aft.

iii. A number of events had forces directed in the plane of the blade.

- Points of application:

i. Circumferential location of the out-of-plane blade force is near the centre of the blade. The calculation of the circumferential location is subject to error because it is calculated using the measured spindle torque and out-of-plane blade force. This calculation ignores the in-plane component of the blade force which can cause spindle torques due to the offset caused by the change in curvature of the blade with radius. The resultant spindle torque is measured accurately, but the in-plant blade force can not be measured.

ii. This location is forward of the location of the steady state hydrodynamic load.

iii. Large impact forces are located low on the blade ($r/R = 0.84$), which is lower than the location of the hydrodynamic load.

iv. The greatest impact load was located at $r/R = 0.69$.

v. The magnitude of the blade forces decrease with the increase of the load application distance from blade's root.

vi. Inclusion of the in-plane component of the total impact force in the calculations of the spindle torque would lead to the shifting of the location of the force vector towards the leading edge.

- Blade Impact Durations (see Section 4.6.1 on the event duration):

  i. An average duration of the blade impact was 78.7° (0.063 seconds).

  ii. The maximum duration of the blade impact was 225° (0.179 seconds).

  iii. Most frequent duration was equal to the average duration.

  iv. Average force event duration is of the same order of magnitude as the blade width, i.e. time required to pass a fixed point in space by the blade.

- Blade Force Impulse:

  i. The maximum blade force impulse was 11.2 kN*s. The average impulse was 2.0 kN*s.

  ii. Maximum bending moment events as well as the maximum blade force events were due to short impulses.

  iii. Impulse analysis shows that the effective mass of the ice blocks being milled by the propellers is contained within the following limits :

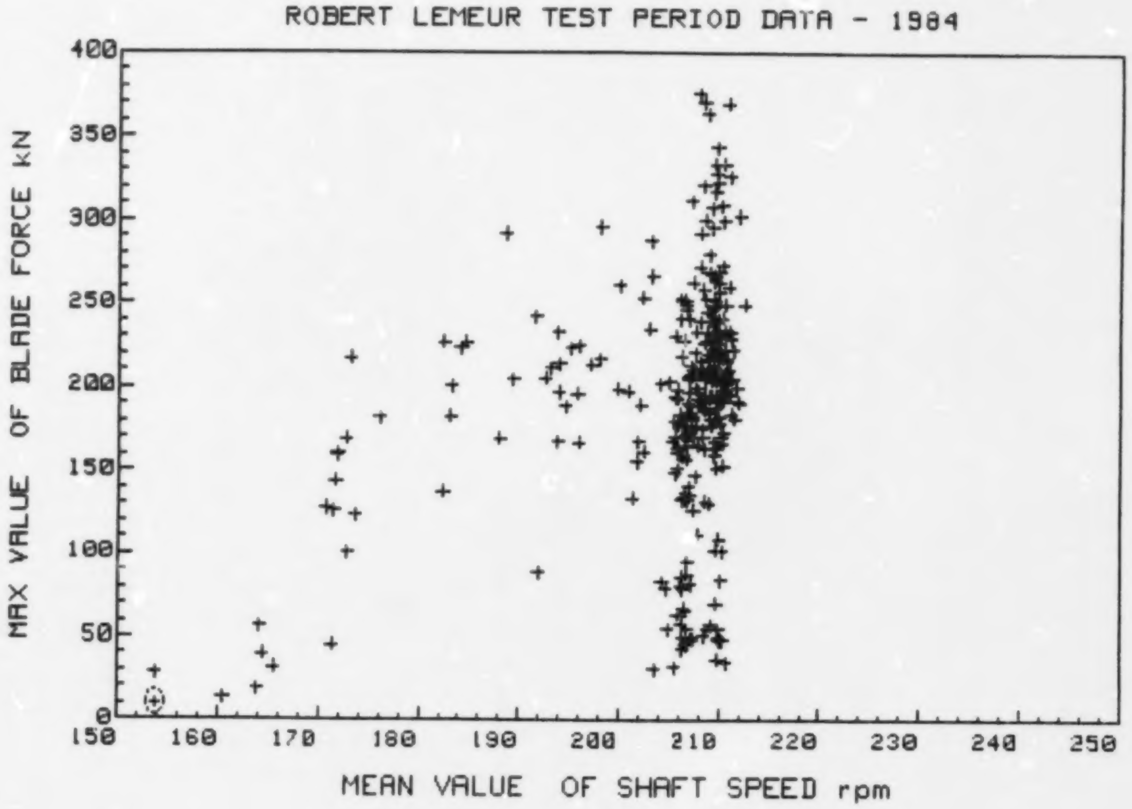
  30 kg < Effective Mass < 1,200 kg

This mass is accounting for the pieces being milled by the blade.

4.4.5 Influence of the Shaft RPM on the Magnitude of the Maximum Blade Force

Figure 4.4.5-1 shows the dependence of the maximum blade force on the mean value of shaft RPM during the interaction events. The following can be observed:

- Maximum values of the blade force increase with the increase of RPM.



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 312

DATA SATISFIED THE FOLLOWING TEST(S)

MEAN VALUE OF SHAFT SPEED > 100 rpm
AND
MEAN VALUE OF PROPELLER PITCH > 0 deg

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: INFLUENCE OF SHAFT RPM ON THE MAXIMUM BLADE FORCE, FOR AHEAD PITCH ANGLES

FIGURE No. 4.4.5-1

- The maximum blade force registered of 375 kN occurred at nearly maximum RPM (208).
- Low blade forces can be observed at high RPM values.

As the change of RPM is often linked with the change of the propeller pitch, the data shown on Figure 4.4.5-1 was regrouped according to the pitch setting. The comparison of ungrouped data (Figure 4.4.5-1) and grouped data (Figures 4.4.5-2 to 4.4.5-5) shows essentially no change in the relationship between RPM and the maximum blade force.

Fitting the trend curve to the data, will obtain the following expression is obtained:

$$(\text{Max Blade Force})_{\text{trend}} = 80 *(\text{RPM} - 160)^{1/4},$$

force being in kN. Note that the maximum blade force contains a hydrodynamic component, which is also dependant on RPM. However, due to its small magnitude [$\pm$10% (35/[375 - 35])] of the total impact force, its influence is disregarded.

Fitting an envelope curve to the data will obtain:

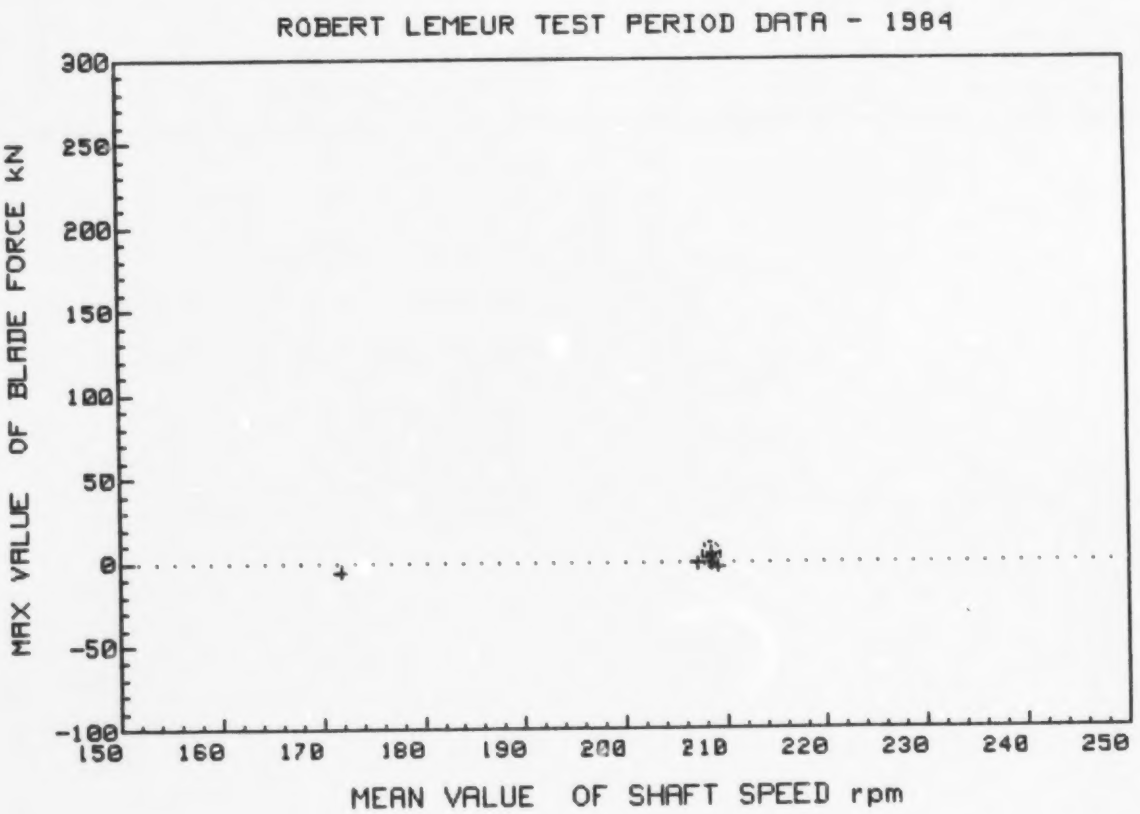
$$(\text{Max Blade Force}) = 48 (\text{RPM} - 150)^{1/2},$$

all units being the same as above.

It is difficult to compare the above trends with the theoretical models since, in reality, RPM is not the isolated variable. RPM influences the amount and velocity of water inflow into the propeller, which in turn may govern the ice inflow velocity. The milling model for example, gives the expression for the ice force being proportional to the axial velocity of the ice and inversely proportional to RPM (Section 7.5 of Milestone 1). The combined influence of these two variables is unknown.

It is shown however that the ship's velocity does not influence the magnitude of the ice impact force (see paragraph 4.4.8). Since ship's velocity is a significant component of water velocity, one may conclude that the axial velocity of ice may not influence the magnitude of the impact force. If so, then the milling model does not reflect the velocity component correctly.

As both plastic and elastic modes of interaction suggest impact forces being proportional to impact

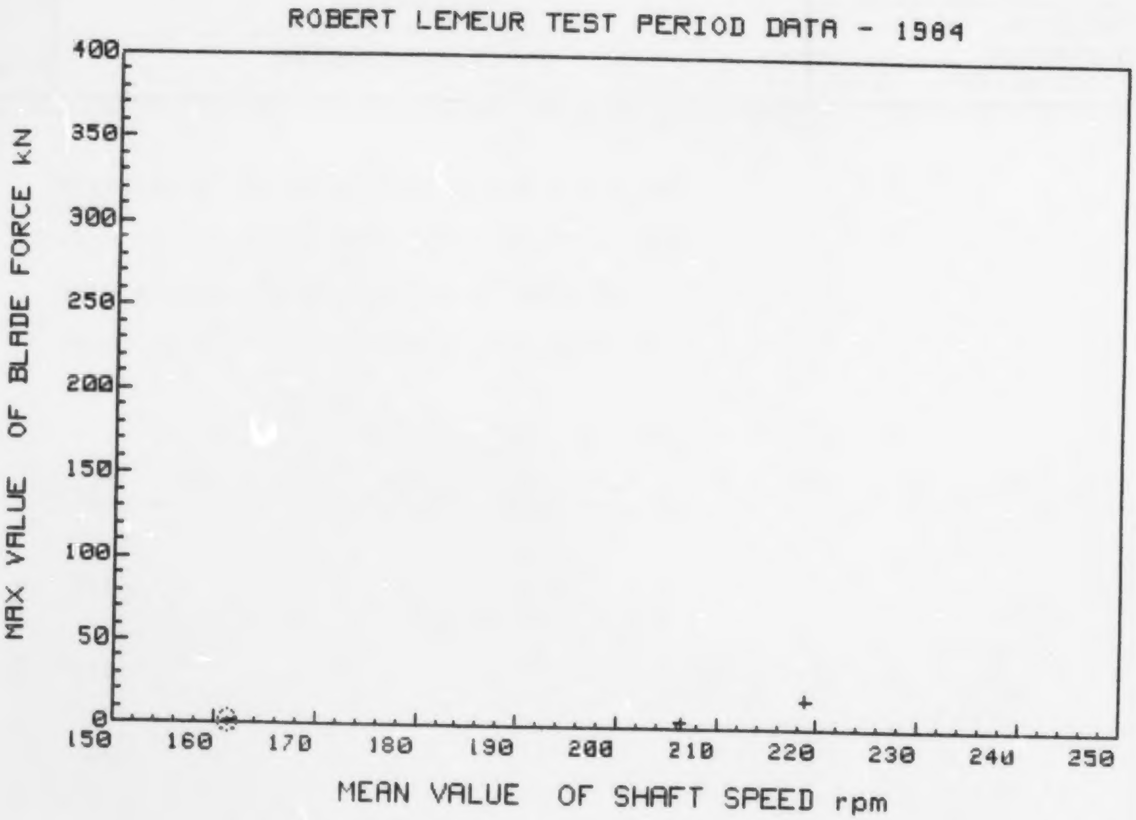


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 7

DATA SATISFIED THE FOLLOWING TEST(S)

MEAN VALUE OF PROPELLER PITCH < -15 deg
AND
MEAN VALUE OF PROPELLER PITCH > -30 deg

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: INFLUENCE OF SHAFT RPM ON THE MAXIMUM BLADE FORCE, FOR PITCH ANGLES -30° < θ < -15
		FIGURE No. 4.4.5-2



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 3

DATA SATISFIED THE FOLLOWING TEST(S)

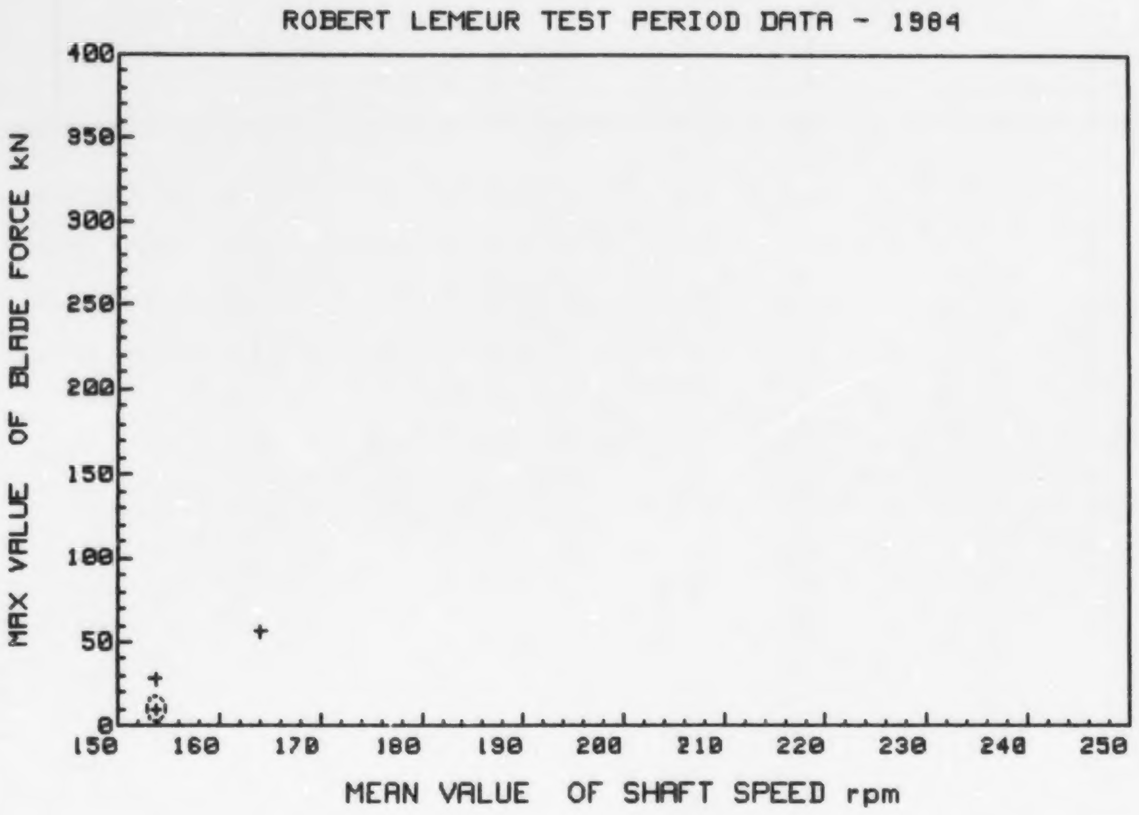
MEAN VALUE OF PROPELLER PITCH > -15 deg
AND
MEAN VALUE OF PROPELLER PITCH < 0 deg

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **INFLUENCE OF SHAFT RPM ON THE MAXIMUM BLADE FORCE FOR PITCH ANGLES $-15^\circ < \theta < 0^\circ$**

FIGURE No. 4.4.5-3

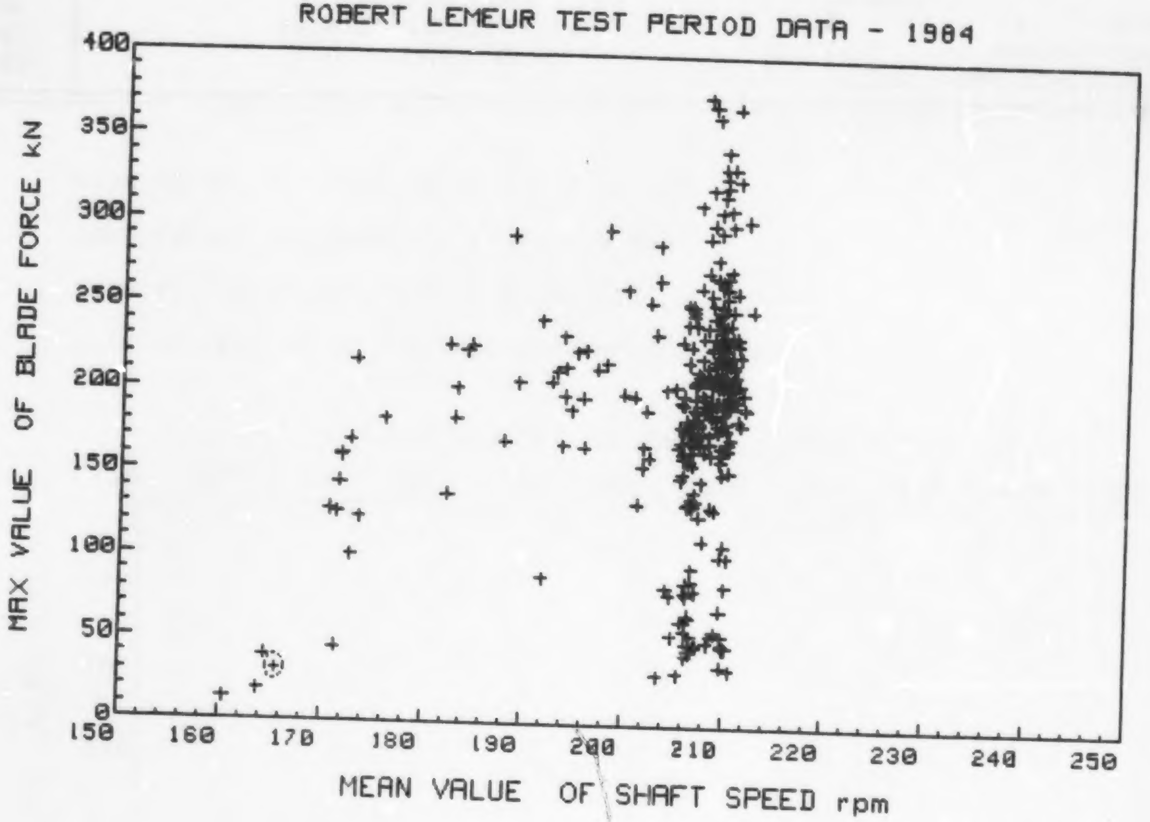


```
TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 3

DATA SATISFIED THE FOLLOWING TEST(S)

MEAN VALUE  OF PROPELLER PITCH > 0 deg
AND
MEAN VALUE  OF PROPELLER PITCH < 15 deg
```

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: INFLUENCE OF SHAFT RPM ON THE MAXIMUM BLADE FORCE FOR PITCH ANGLES 0 < θ < 15°** **FIGURE No. 4.4.5-4**



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 309

DATA SATISFIED THE FOLLOWING TEST(S)

MEAN VALUE OF PROPELLER PITCH > 15 deg
AND
MEAN VALUE OF PROPELLER PITCH < 30 deg

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: INFLUENCE OF SHAFT RPM ON THE MAXIMUM BLADE FORCE FOR PITCH ANGLES 15° < θ < 30°** **FIGURE No. 4.4.5-5**

velocity they do not model velocity component correctly either.

Only the brittle mode of ice impact suggests that the velocity dependence may be less than proportional due to the limit impact force being governed by the ability of ice block to sustain the load before cracking. However, the data is not precise enough to confirm, or deny this stipulation.

4.4.6 Influence of Propeller Pitch on the Magnitude of Ice Impact Blade Force

Figure 4.4.6-1 shows the distribution of the mean value of propeller pitch setting during the tests. The mean value of the pitch settings was approximately 21°. The maximum was 26°. Astern pitch was used on few occasions. The mean pitch was less than the maximum design pitch by approximately 10%.

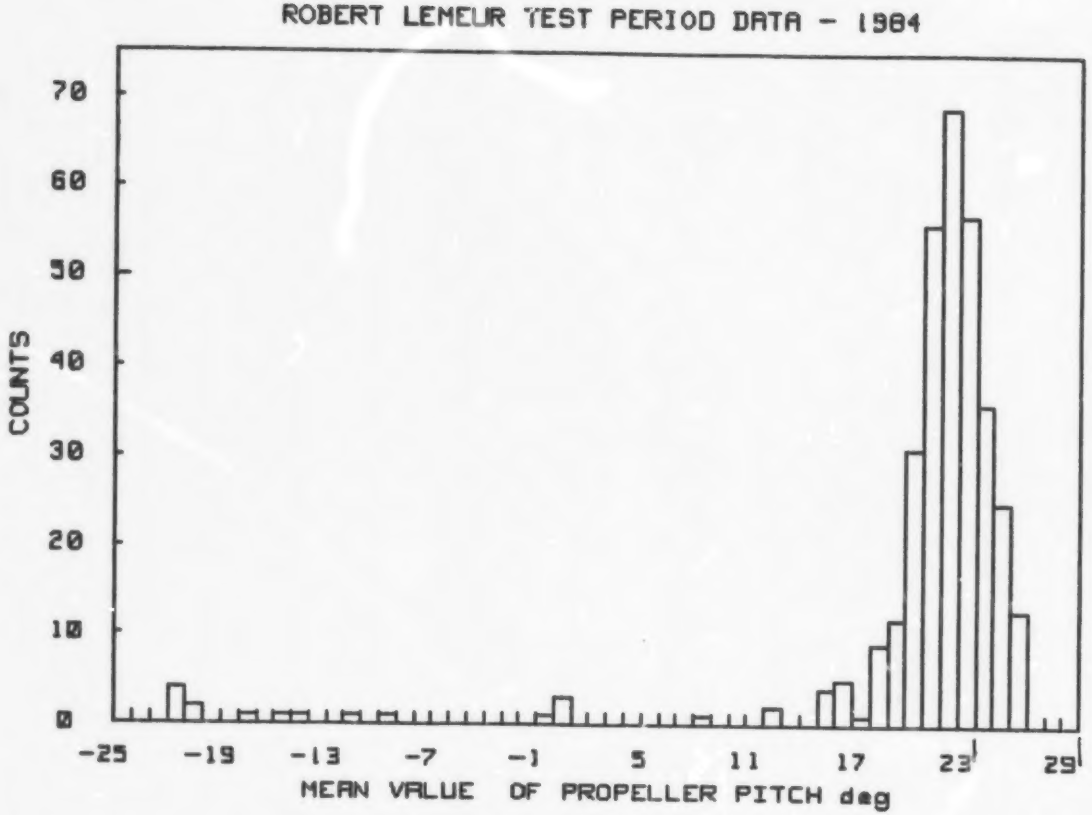
Figure 4.4.6-2 shows the influence of the propeller pitch setting on the maximum value of blade impact force. The following observations can be made:

- Low positive and high negative pitch settings produced little blade impact forces.
- For pitch settings larger than 16° there is a dramatic increase of impact forces (there is also a dramatic increase of the number of events).
- For pitch settings between 16° and 26° there is no detectable influence of pitch on the maximum blade force.
- The maximum value of the blade force occurred at less than maximum pitch setting (pitch angle 19°).

It is difficult to extract the pitch influence from other parameters, all of which are pitch dependent. For example: RPM, ship's velocity, water inflow velocity, shaft torque are all pitch dependant.

Comparison with the theoretical model which suggests that the higher the pitch, the larger the blade force shows that although the trend predicted is confirmed, actual changes of pitch angle were not large enough to show this dependency clearly. For the majority of pitch settings during the trials, pitch did not influence the magnitude of the blade force appreciably.

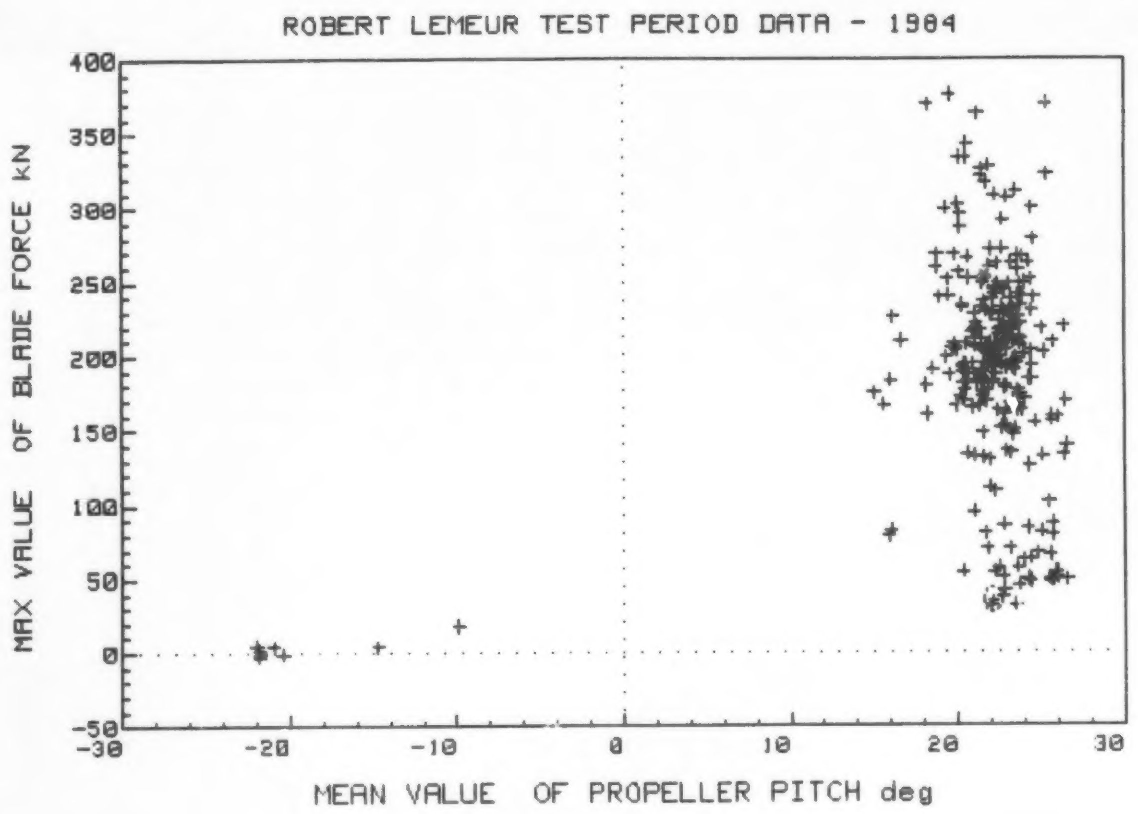
Figure 4.4.6-3 shows the influence of the pitch angle on the blade spindle torque. No clear trend can be discovered, although there is some decrease of the blade



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 336
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:20.827
AND ITS STANDARD DEVIATION IS:7.9147

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: STATISTICS OF THE MEAN VALUES OF PROPELLER PITCH DURING THE TESTS FIGURE No. 4.4.6-1

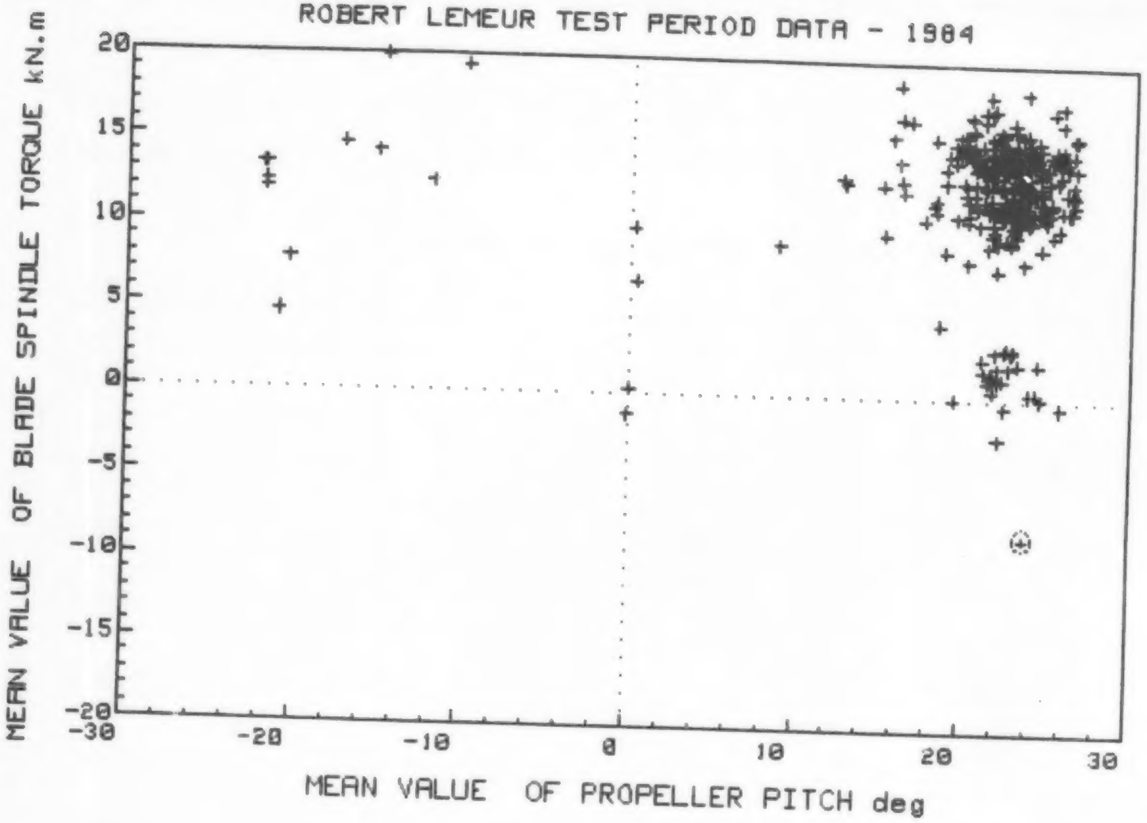


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 276

DATA SATISFIED THE FOLLOWING TEST(S)

MEAN VALUE OF SHAFT SPEED > 200 rpm

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:INFLUENCE OF PROP. PITCH ON THE MAXIMUM VALUE OF BLADE FORCE FOR SHAFT SPEED > 200 RPM** **FIGURE No. 4.4.6-2**



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 336

ALL DATA USED

CANADIAN
MARINE
DRILLING
LIMITED

MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE: INFLUENCE OF PROP. PITCH ON THE MEAN VALUE OF SPINDLE TORQUE

FIGURE No. 4.4.6-3

spindle torque with the decrease of propeller pitch. The amount of data is insufficient however to validate this observation.

4.4.7 Influence of Rudder Angle on the Magnitude of Maximum Blade Force

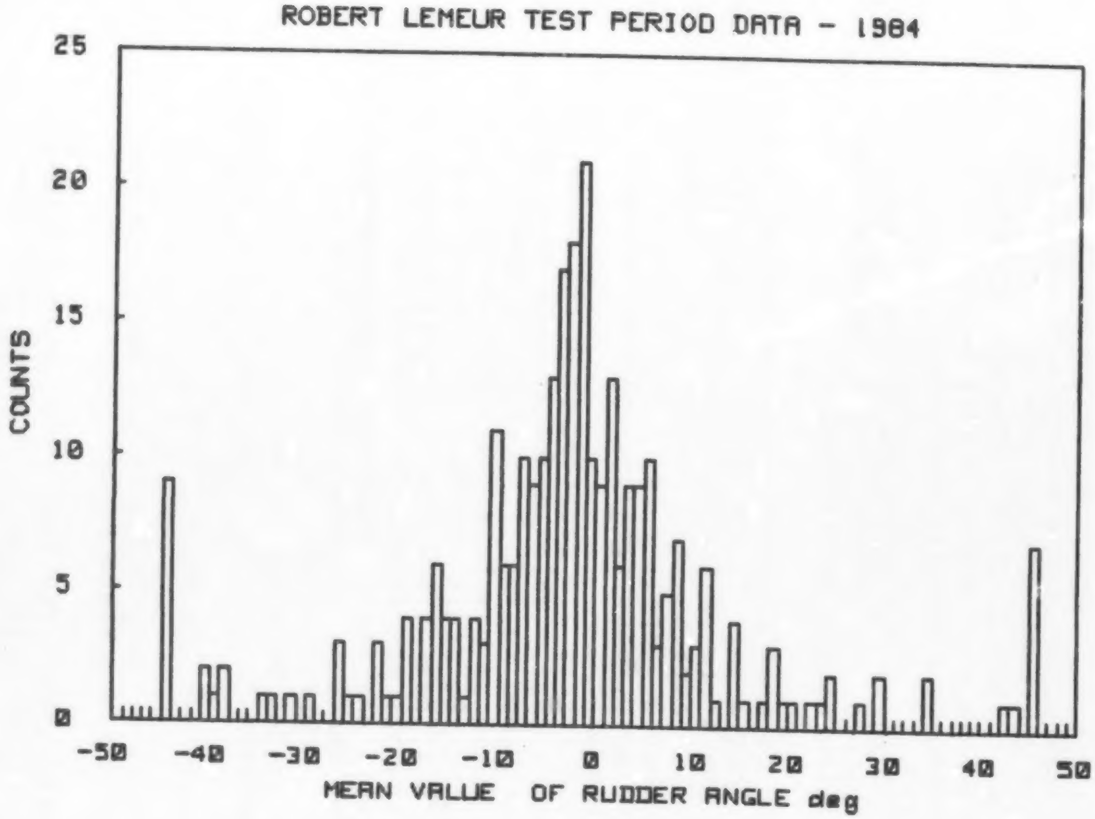
Figure 4.4.7-1 shows the distribution of mean values of rudder angles during the tests. Distribution is highly symmetrical, with mean value of rudder angle being -2.6° (- denotes port) and the maximum positions of the rudder angle at 45° both port and starboard. The distribution shows that the rudder-to-port commands were nearly equally frequent to the rudder-to-starboard commands.

Figure 4.4.7-2 shows the influence of the rudder angle on the magnitude of the maximum blade forces during the tests. The following can be observed:

- Interaction is more frequent when the rudders are turned to port. This is explained by realizing that when the stern of the ship is swinging to starboard, it "attacks" the channel edge. Since the instrumented propeller is on the starboard side of the ship, more frequent interaction with ice is expected.
- Higher blade forces are recorded when the rudders are turned to port. This is due to more frequent interactions leading, statistically, to higher loads. It is also possible that compressing of ice blocks by the stern of the ship creates the ice block confinement leading to the increased loads during the ice/propeller interaction.
- The highest blade impact force has been observed at a rudder angle of 4° to starboard. However, the "near - highest" three impacts were recorded at rudder angles between 10° and 40° to port.
- All of the impacts collected during the rudder turned-to-port between 14° and 45° condition, were of high magnitude (Force > 150 kN).

4.4.8 Influence of Ship Speed on the Magnitude and Orientation of the Maximum Blade Force

- Hydrodynamic Load: The influence of ship's speed on the mean value of the blade force is shown on Figure 4.4.1-1. The mean value reflects predominately hydrodynamic components.

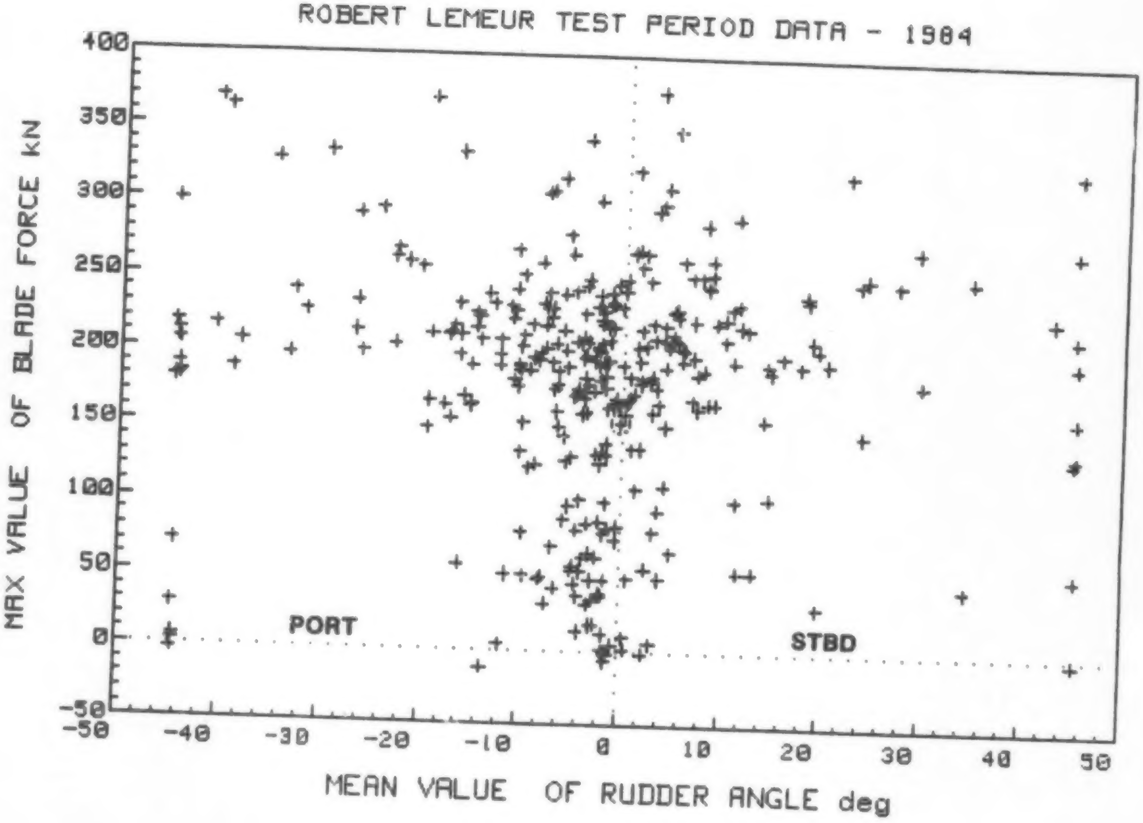


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 301
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:-2.615
AND ITS STANDARD DEVIATION IS:15.920

DATA SATISFIED THE FOLLOWING TEST(S)

FIRST TYPE OF TYPE OF INTERACTION > 0

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: STATISTICS OF RUDDER ANGLE DURING THE TESTS
		FIGURE No. 4.4.7-1



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 336

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: INFLUENCE OF THE RUDDER ANGLE ON THE MAXIMUM VALUE OF BLADE FORCE FIGURE No. 4.4.7-2

The following observations can be made:

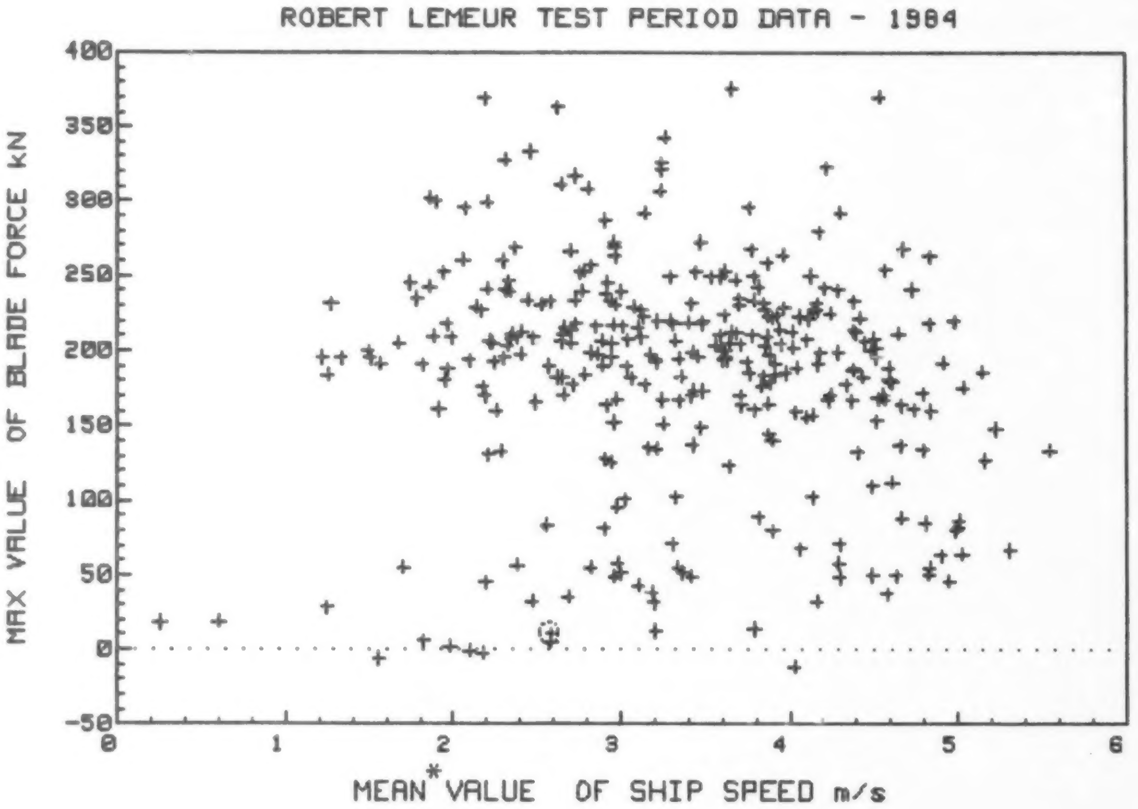
- The mean value of blade force decreases with an increase of ship's speed. The rate of the decrease is (2.9 kN)/(1 m/s).
- The extrapolated bollard condition gives the blade force value of 51.5 kN, which translates into the total bollard pull of 51.5 kN*4*2*2 = 80 tonnes (assuming a convential 50-50 split of thrust between nozzles and propellers).
- The higher the ship's speed the lower the observed fluctuation of the mean blade force. This is partially due to the fact that the propeller - induced water velocity becomes a lesser component of the total water inflow velocity and the flow is "smoothed" by an increase of ship speed.
- The best fit straight line through the data is:

Mean Blade Force = 51.5 - 2.92 *(ship speed), where force is in kN and ship speed is in m/s.

- Ice Induced Load: Figure 4.4.8-1 shows the dependence of the maximum blade force on the mean value of ship's speed. No correlation between these two variables can be detected. This confirms the theory, which stipulates that the impact velocity of the blade is largely governed by the rotational speed of the blade and to a very small extent by the ship velocity. This is evident the Figure 7.3.4. of the Milestone 1 where the total blade velocity against water is 32.8 m/s for V_{ship} = 0 m/s and 33.3 m/s for V_{ship} = 6m/s.

Figure 4.4.8-2 shows the influence of ship's speed on the position of impact of blade on ice. The following observations can be made:

- All of the data points presented are grouped around two angular positions: 45° and 225° (measured from the top vertical point counter-clockwise). Since the blade itself can be subscribed into a 60° angle, the actual positions of the leading edge at the impact are 75° and 255°. This shows that the ice is being hit at two nearly diagonally opposite locations: 15° above the horizontal plane passing through the propeller shaft and 15° below it. This is contrary to the expectation that ice is located on the top of the nozzle tunnel.

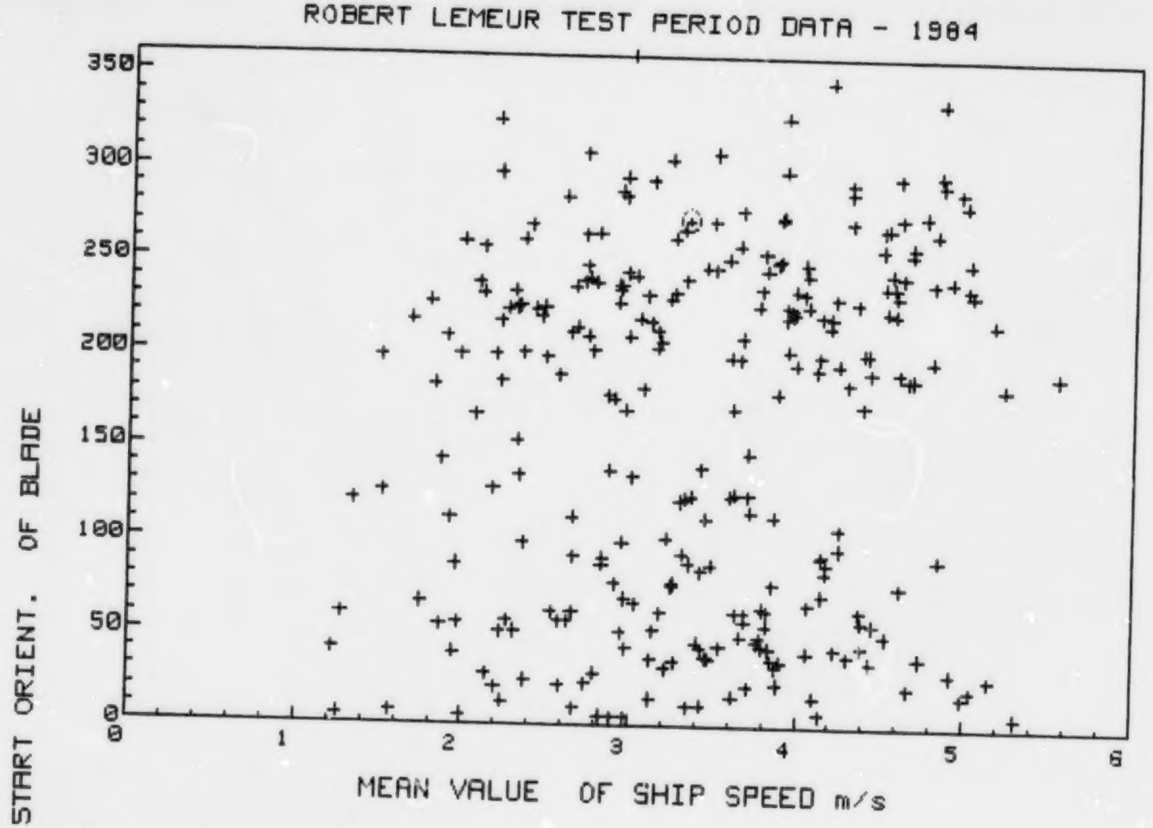


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 320

ALL DATA USED

* AVERAGE SPEED DURING 7 sec. EVENT DURATION

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: INFLUENCE OF SHIP'S SPEED ON THE MAXIMUM VALUE OF BLADE FORCE
		FIGURE No. 4.4.8-1



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 279

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: INFLUENCE OF SHIP'S SPEED ON THE POSITION OF FIRST CONTACT BETWEEN BLADE AND ICE**
		FIGURE No. 4.4.8-2

- For ship's speeds less than 3.9 m/s, the blade is hitting the ice at the locations specified above, but for higher speeds a "shadow" develops at about 150° (leading edge 180°) where no ice is being hit. This can be explained by the presence of the sole piece, which shields the propeller from the ice passing by.
- At lower ship speeds, the blade impacts the ice in the 90° position (inboard), at high speeds the position is shifted to approximately 200° (outboard). This suggests, that at low speeds ice is present in the middle of the ice island while for high speeds, more ice is present on the outside.

4.4.9 Conclusions

- Shaft RPM:

i. Increase of RPM leads to an incrase of the impact forces.
ii. The increase can be expressed by:

$$(\text{Max Blade Force})_{\text{trend}} = 80\ (\text{RPM} - 160)^{1/4}.$$

This can be attributed to:

a. Lower suction producing fewer interactions.
b. Smaller angle of attack against ice.
c. Shorter time operating at reduced pitch, hence fewer interactions.

iii. Different pitch settings do not alter this dependency.
iv. Experiments do not confirm the theoretical model which predicts stronger (directly proportional) dependence of impact force on RPM.

- Propeller Pitch:

i. Within ± 30% of the average pitch setting during the trials (20.8°), no influence of the pitch setting on the magnitude of blade force was detected.
ii. Forces drop drastically with the decrease of pitch below 16°.

iii. Negative pitch produced very low impact forces.
iv. Change of pitch does not influence the blade spindle torque.
v. The data neither confirms, nor denies the theoretical model.

- Rudder Angle:

i. While doing the ice-management duties in drillship defence, MV Robert LeMeur executed nearly the same amount of maneuvers to port as to starboard.
ii. Interactions between ice and the starboard propeller were more frequent when the ship was turning to port due to the stern of the ship swinging against the channel edge.
iii. With rudders turned to port, ice/propeller interactions on the instrumented propeller were more severe than with rudders turned to starboard.

- Ship's Speed:

i. Hydrodynamic load on the blade can be expressed by:
$(\text{Blade Force})_{\text{hydro}} = 51.5 - 2.92 * (\text{ship's speed})$.
ii. There is no correlation between ship's speed and the magritude of the maximum blade force due to ice impacts.
iii. Data collected confirms theoretical model findings.
iv. Ship's speed influences the location at which ice contacts the blade.

4.5 Shaft Torque And Thrust

4.5.1 Shaft Torque

- Open Water Condition: Open water torque signal fluctuates approximately 25% about the mean during each revolution.[7] Maximum continuous torque rating is calculated to be 151 kN*m. The mean value of shaft torque during the tests was 142 kN*m (94% of the maximum). Figure 4.5.1-1 shows the distribution of the mean shaft torques measured during the tests. The most frequent torque was approximately 150 kN * m.

---

[7] (-Min + Max)/Mean

- Ice Condition: Figure 4.5.1-2 shows the distribution of the maximum values of total shaft torques recorded during the ice interaction events. The mean of these values was 204 kN*m (increase of 44% (204/142) above the average), and the maximum torque recorded was 305 kN*m (twice the maximum rated torque) and 2.15 times the average torque recorded during the trials.

The maximum torque event was event No. 117 which was categorized as a milling event. During this event, the torque fluctuated 30% about the mean. The ship speed was 2.2 m/s and the rudder angle was 19.5°, to port. As a result of the high torque level sustained during this event, shaft RPM, held at 195 dropped to 180, which resulted in a significant reduction of shaft torque (see Figure 4.5.1-4).

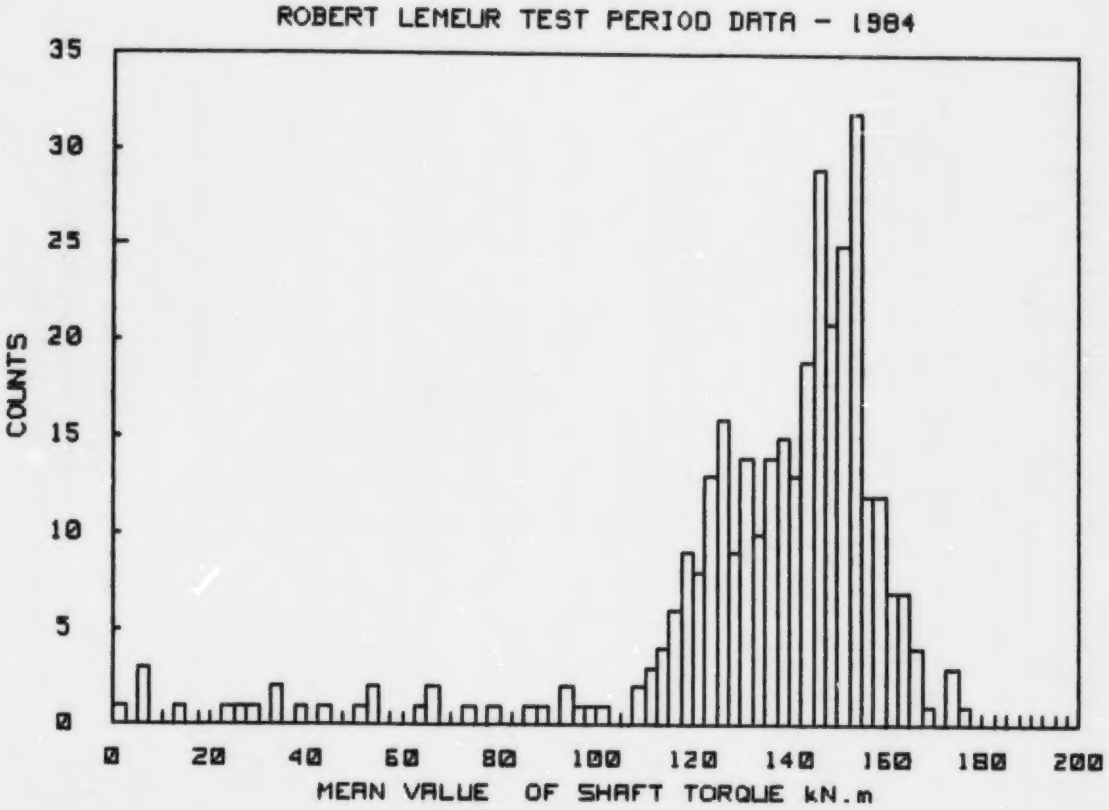
Figure 4.5.1-3 shows the correlation between the maximum torque and maximum thrust recorded during the trials. The following can be observed:

- Maximum ice induced torques are associated with low thrusts.
- Maximum thrust values occur at torques slightly exceeding the maximum continuous rated torque of 151 kN*m.
- Increases of torque above 151 kN*m are associated, in general, with decreases of the maximum thrust level.

All of the torque events show a very pronounced presence of the fundamental frequency of shaft torsional vibrations at 3.58 Hz.

Presenting the maximum torque recorded on the shaft gauges as:

$Q_{max} = \Delta Q_{ice} + 4Q_{ow}$, where Q_{ow} denotes the torque developed by one blade in the steady state open water condition, and ΔQ_{ice} expresses the net increase



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 336
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:134.92
AND ITS STANDARD DEVIATION IS:29.164

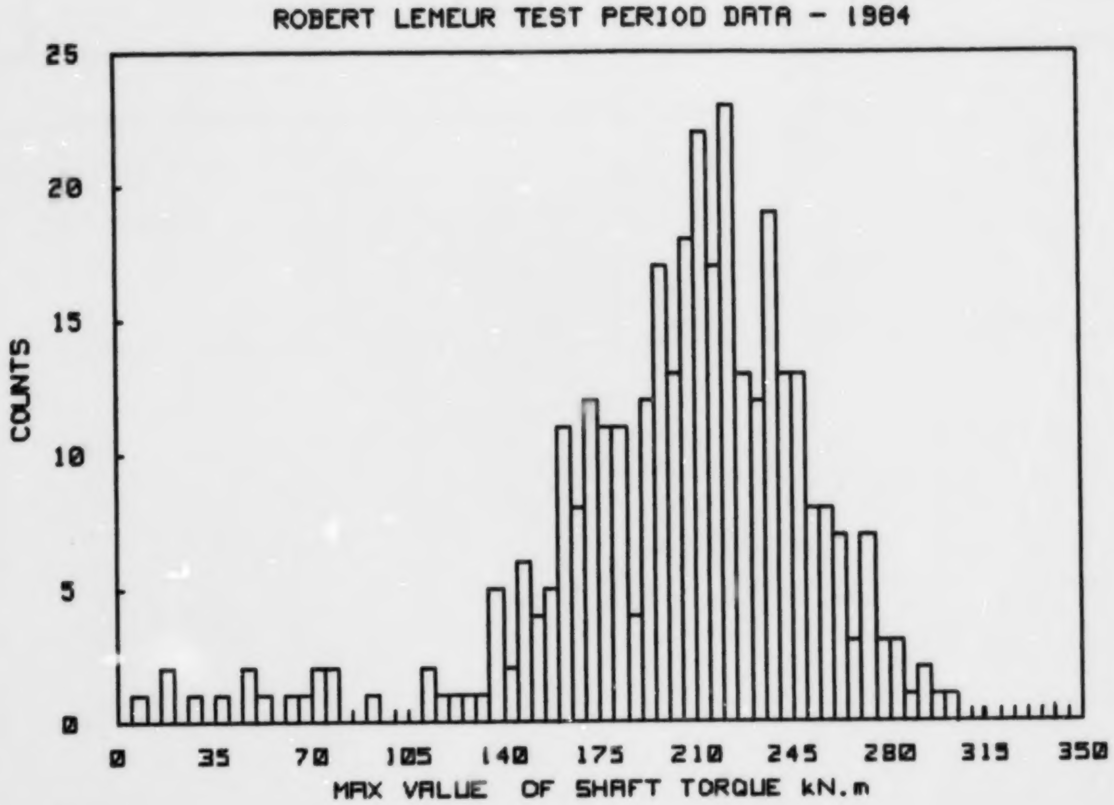
ALL DATA USED

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
HISTOGRAM OF MEAN VALUES OF SHAFT TORQUE

FIGURE No. 4.5.1-1



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 336
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:204.20
AND ITS STANDARD DEVIATION IS:49.005

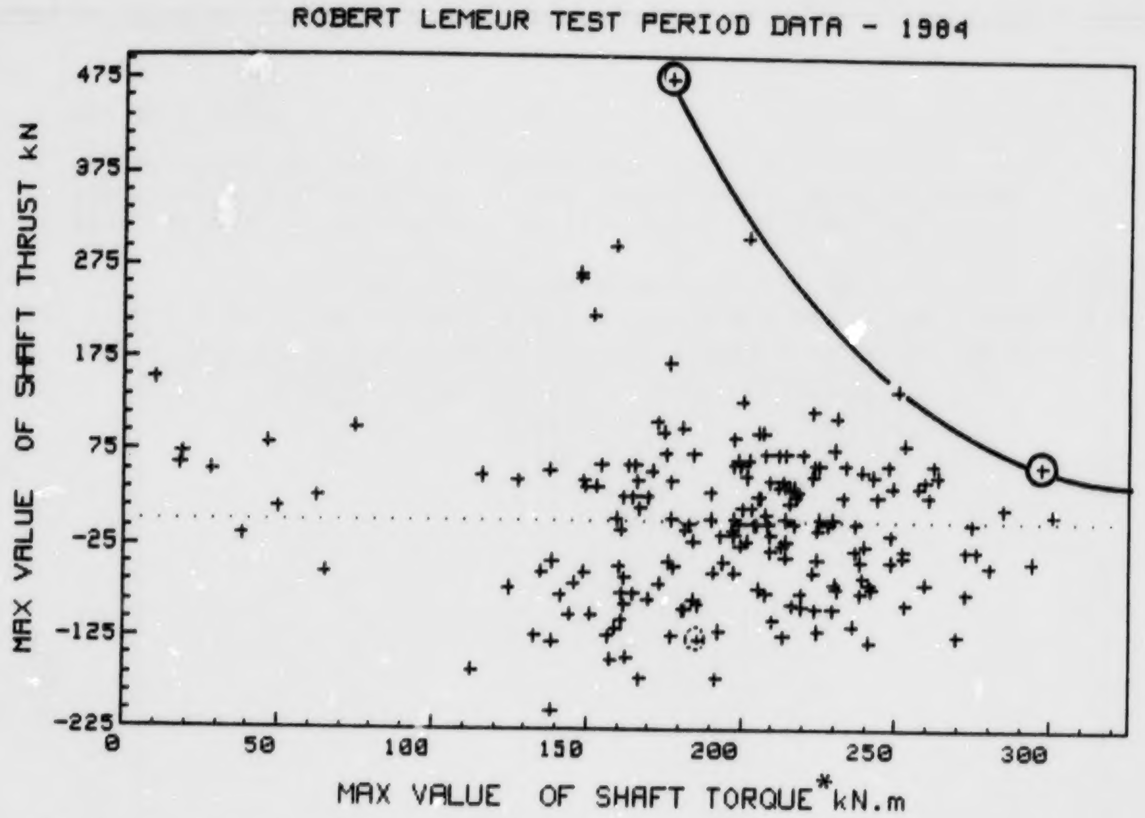
ALL DATA USED

CANADIAN
MARINE
DRILLING
LIMITED

MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE: **HISTOGRAM OF MAXIMUM VALUES**
OF SHAFT TORQUE

FIGURE No. 4.5.1-2

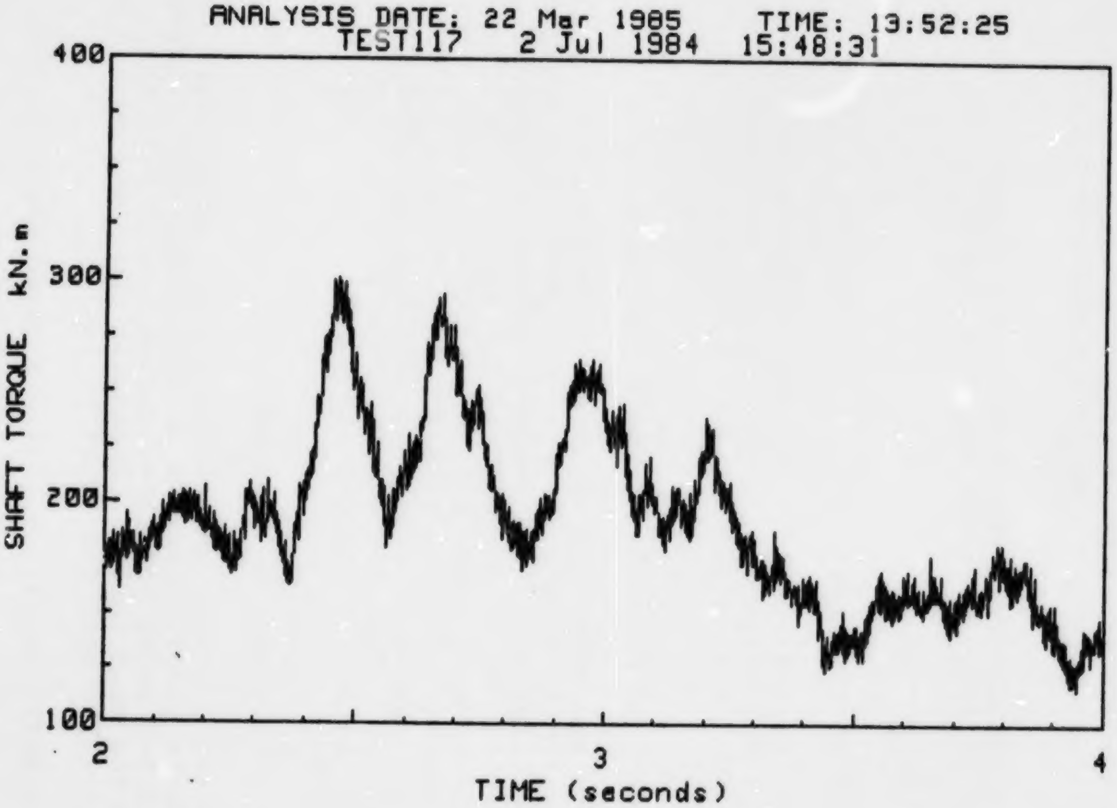


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 193

ALL DATA USED

* TORQUE IS COMPOSED OF HYDRODYNAMIC AND ICE INDUCED TORQUES

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: MAXIMUM VALUE OF SHAFT TORQUE VERSUS THE MAXIMUM VALUE OF SHAFT THRUST
		FIGURE No. 4.5.1-3



CANADIAN
MARINE
DRILLING
LIMITED

MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE:
HISTORY OF THE MAXIMUM TORQUE EVENT

FIGURE No. 4.5.1-4

of torque on one blade, we can formulate the following expression:

Total Torque = Ice Torque + Hydrodynamic torque, or:

$2 * 4Q_{ow} = \Delta Q_{ice} + 4Q_{ow}$, which yields

$\Delta Q_{ice} = 4Q_{ow}$, that is:

The maximum increase of torque on one blade milling the ice was four times the maximum continuous torque of that blade in the bollard condition.

If we assume that the blade lost its hydrodynamic load while milling, then the equation yields:

$$\Delta Q_{ice} = 5Q_{ow}$$

4.5.2 Shaft Thrust

- Hydrodynamic Load: The mean values of thrust measured in the shaft during the open water transits (not of full power) are shown on Figure 4.5.2-1. The best fit equation is:

Thrust = 283 - 9.5 * (Ship Velocity)

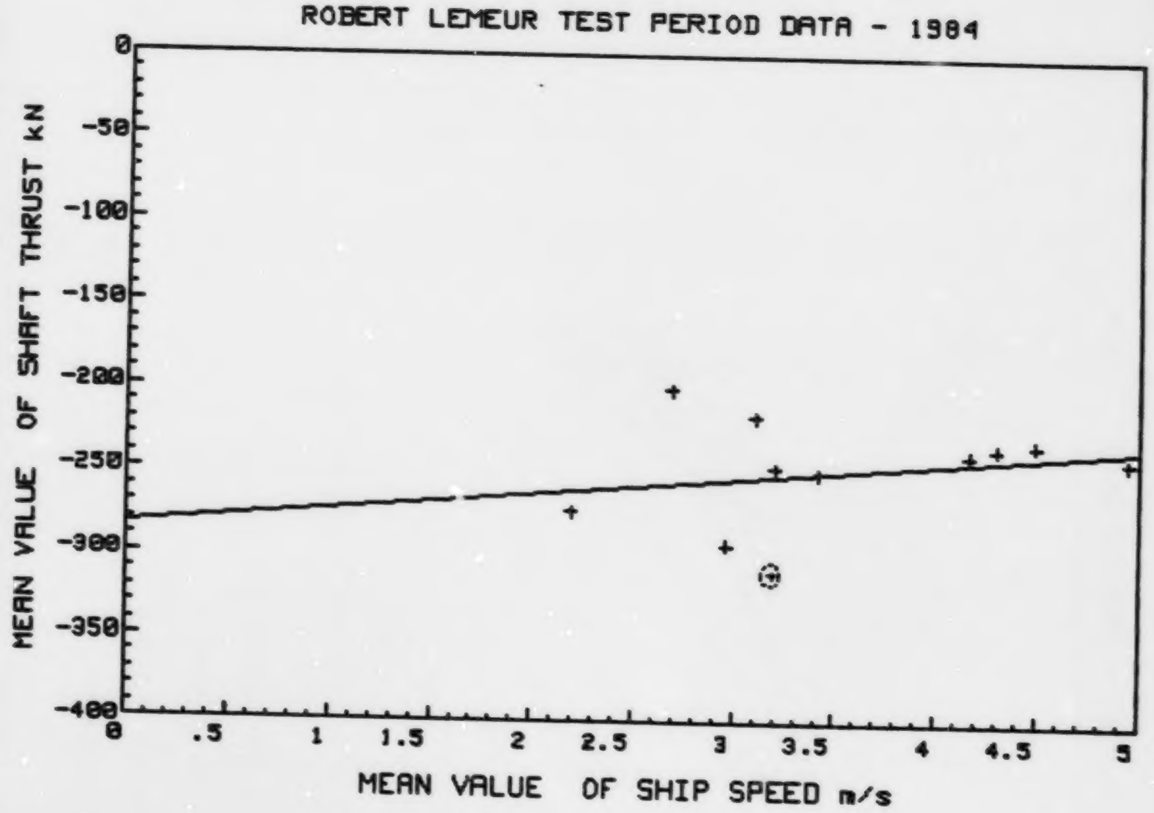
where the thrust is measured in kN and ship's velocity is in m/s. Thrust in ahead direction has minus sign as it induces compression of the shaft. Shaft thrust at the bollard is then -283 kN which compares well with -276 kN predicted by LIPS. The decrease of the shaft thrust with speed is -9.5 kN/m/s, which is more than LIPS has predicted (-6.6 kN/m/s). Propeller thrust compares reasonably well with the sum of the calculated blade forces at the bollard:

4 * (-51.5 kN) = -206 kN (72%)

However a proper correction for the pitch angle has to be made in order to arrive at more comparable figures. Figure 4.5.2-2 shows the inter-dependance of mean shaft thrust on the mean torque. (including fluctuations due to ice loads). The best fit equation is:

mean shaft thrust = 5.3 + 2 (mean shaft torque)

For a nominal torque of 151 kN, the calculated thrust becomes -307 kN, which is 1.08 times the rated bollard thrust. This increase is due to the ice interaction effects, as well as due to the changed mode of operations in ice (icebreaking mode).


ROBERT LEMEUR TEST PERIOD DATA - 1984

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TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 11

DATA SATISFIED THE FOLLOWING TEST(S)

FIRST TYPE  OF TYPE OF INTERACTION = 0
AND
SHIP DIRECT.  OF INTER.0, ICE or WATER, DIR. = 1
AND
MEAN VALUE  OF SHAFT TORQUE > 100 kN.m

Y =  9.489016179 *X + -283.242295204
```
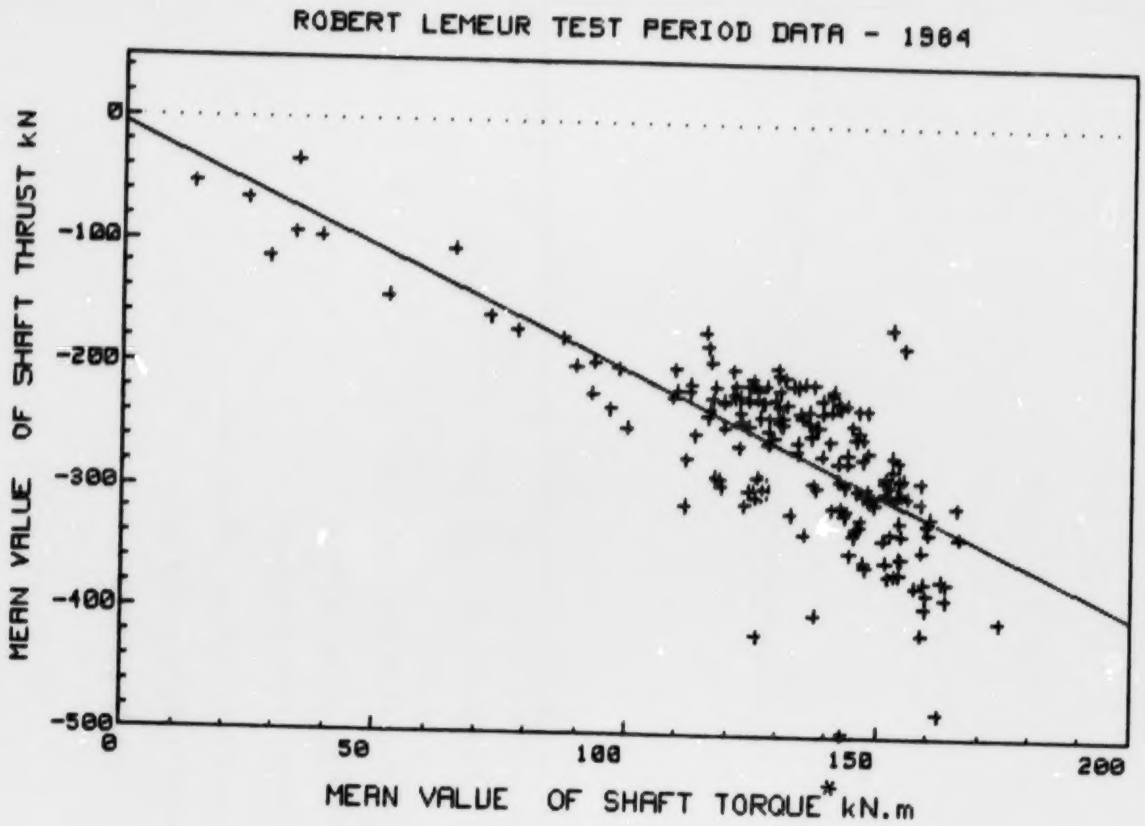

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **DEPENDANCE OF THE MEAN VALUE OF SHAFT THRUST ON SHIP'S SPEED**
		FIGURE No. 4.5.2-1



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 183

DATA SATISFIED THE FOLLOWING TEST(S)

MEAN VALUE OF PROPELLER PITCH > 5 deg

Y = -1.97492617084 *X + -5.34755068558

* TOTAL TORQUE

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: DEPENDANCE OF THE MEAN VALUE OF SHAFT THRUST ON THE MEAN VALUE OF SHAFT TORQUE** **FIGURE No. 4.5.2-2**

Thrust excursions during the open water sailings were 74% about the mean and these excursions occur at the blade frequency of 3.5 Hz.

- Ice Interaction Condition: Figure 4.5.2-3 shows the histogram of the maximum values of the shaft thrust recorded during the tests, for both ahead and astern conditions. The maximum (positive values) of the maximum thrust recorded was 480 kN, which is -170% of the estimated bollard thrust.

Figure 4.5.2-4 shows the minimum values of the thrust. The extreme value of -1,150 kN (4.6 times the bollard thrust) is suspect due to gauge signal drifts during tests.

4.5.3 Influence of the Rudder Angle on Torque and Thrust

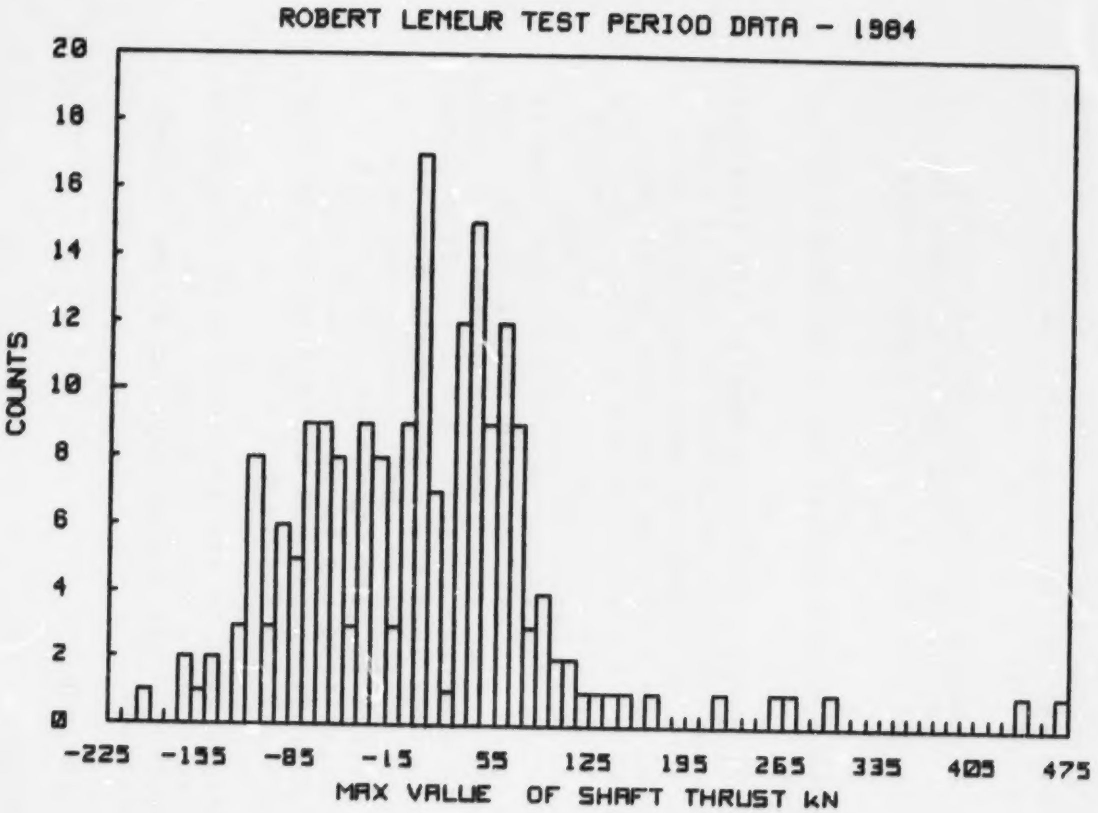
While observing the ship's wake during the five days of testing, it became apparent that the periods of high rudder angles to port or starboard were associated with heavy vibrations of the stern and propeller slipstream breakdown. Therefore, a hypothesis was launched that the rudder angle may influence significantly the performance of the propeller without impacting ice interference. To test this hypothesis, mean values of shaft torque (Figure 4.5.3-2) were plotted against the mean rudder angle. The mean value of shaft thrust as a function of the mean value of rudder angle is plotted on Figure 4.5.3-1. From these figures we can conclude that the rudder angle does not influence the average values of shaft torque, but when the rudder angle is turned to port, the mean shaft thrust increases. A similar tendency is observed with the maximum values of shaft thrust and minimum values of shaft torque (Figure 4.5.3-3 and Figure 4.5.3-4).

These findings lead to the abolishment of the above hypothesis. Consequently, the vibrations of the stern should be attributed to the rudder excited forces rather than propeller excited.

4.5.4 Conclusions

- Shaft Torque:

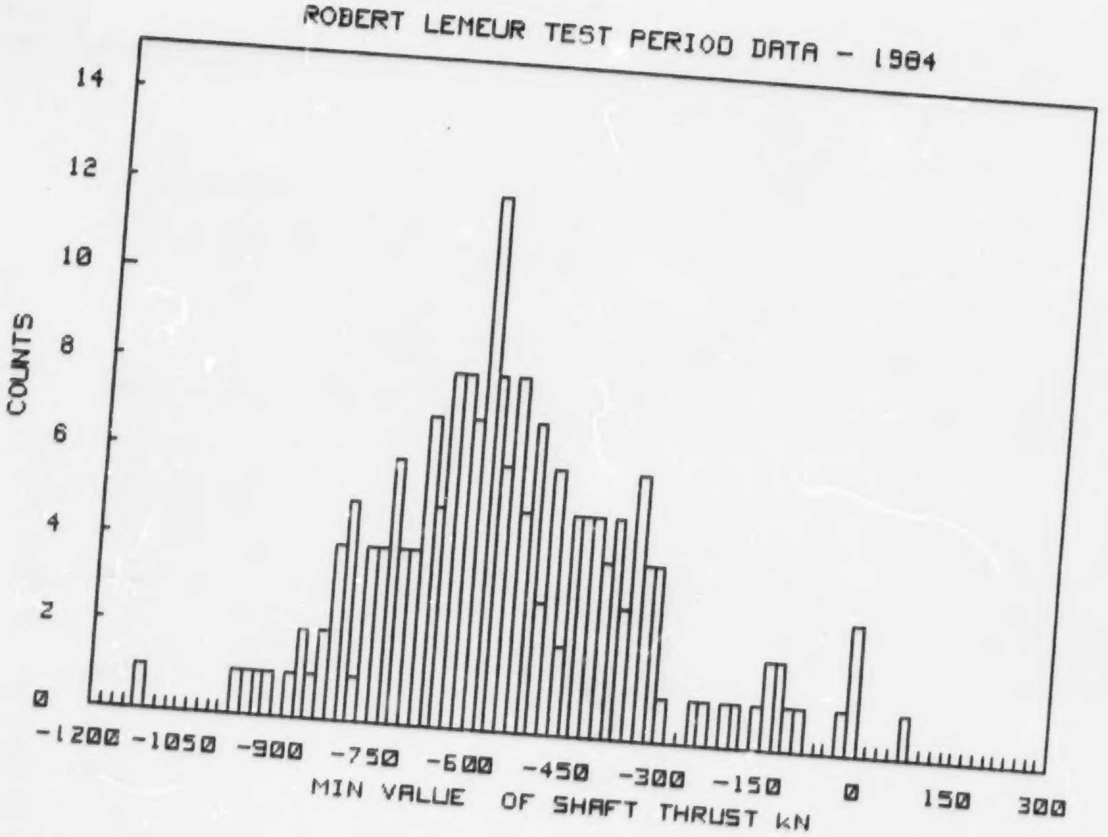
i. The maximum shaft torque recorded was 305 kN * m, which is twice the maximum bollard condition torque.
ii. There is no correlation between the maximum torque and the maximum thrust.



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 193
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:.42901
AND ITS STANDARD DEVIATION IS:93.105

ALL DATA USED

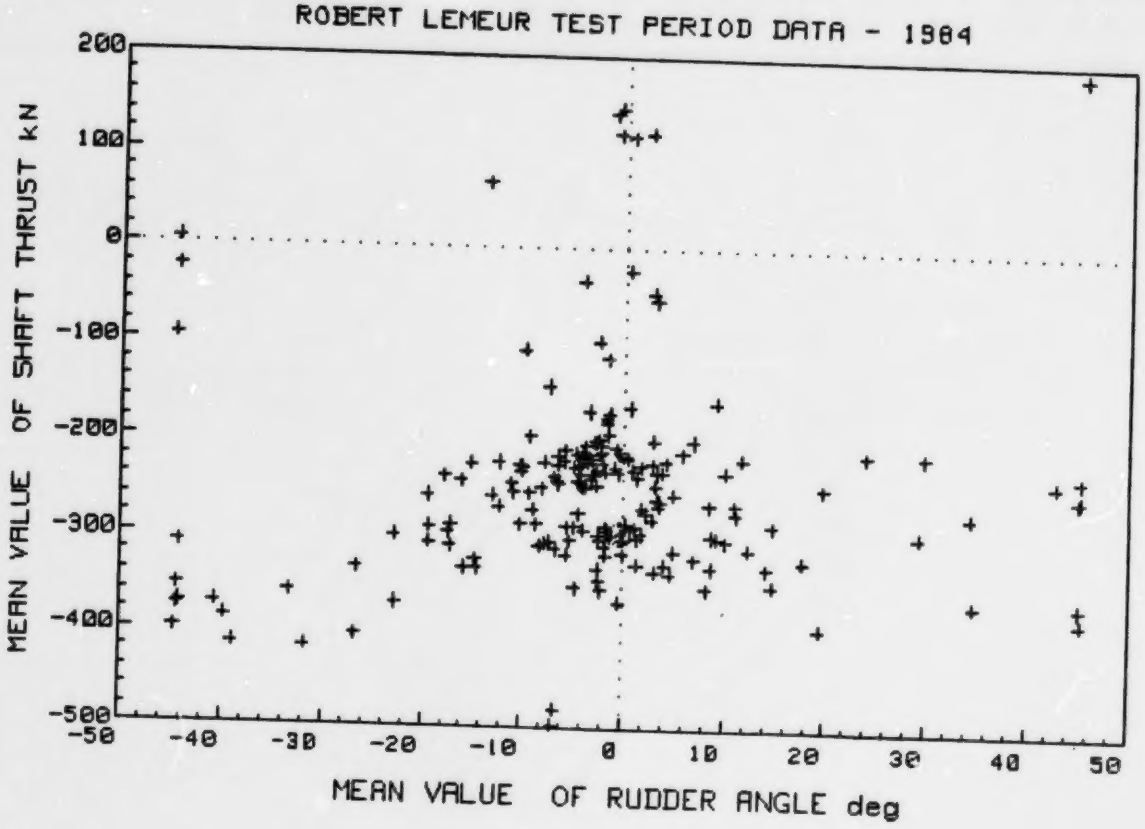
CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: HISTOGRAM OF THE MAXIMUM VALUES OF SHAFT THRUST
		FIGURE No. 4.5.2-3



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 193
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:-556.7
AND ITS STANDARD DEVIATION IS:202.98

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: HISTOGRAM OF THE MINIMUM VALUES OF SHAFT THRUST
		FIGURE No. 4.5.2-4



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 193

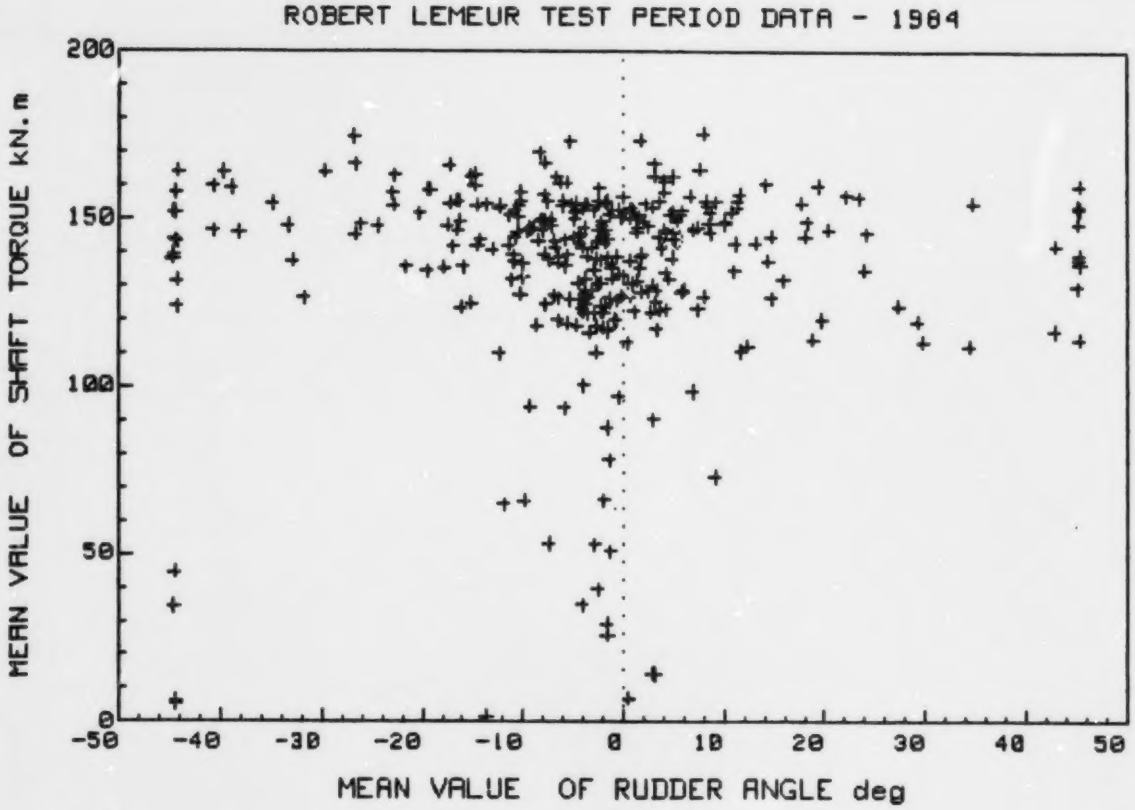
ALL DATA USED

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: INFLUENCE OF RUDDER ANGLE ON THE MEAN VALUE OF SHAFT THRUST

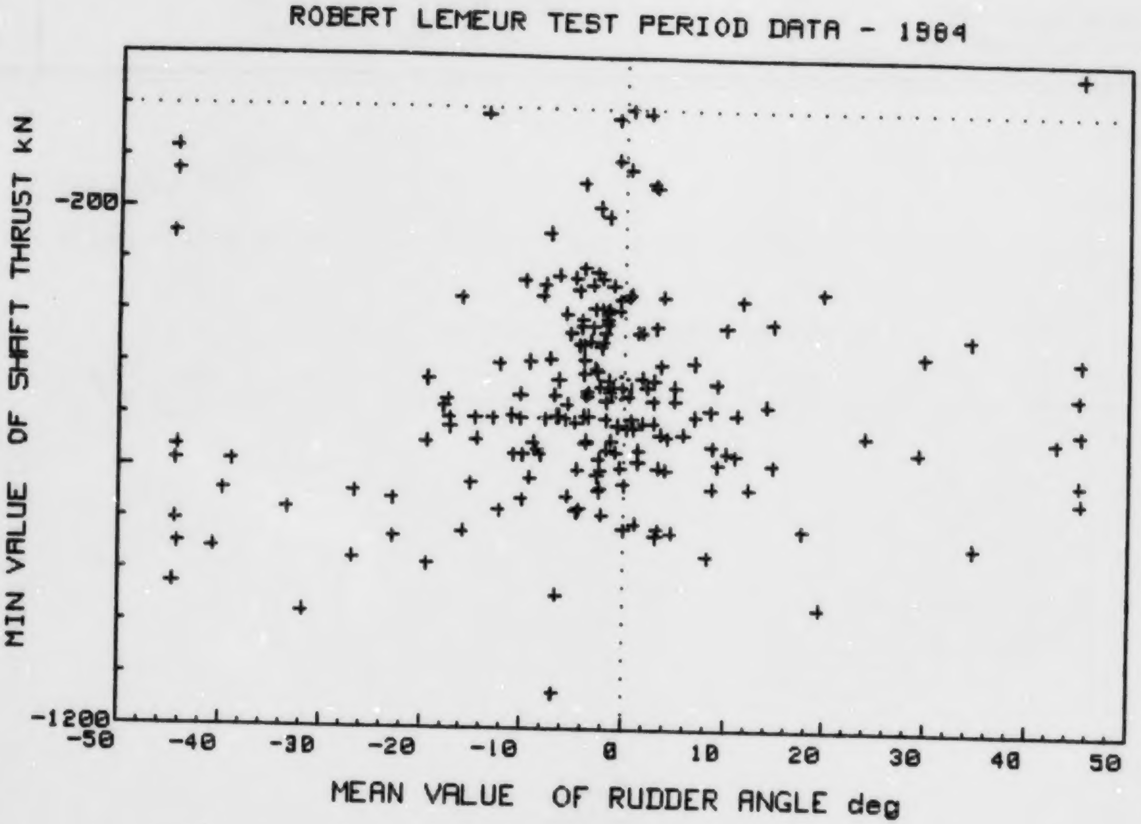
FIGURE No. 4.5.3-1



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 336

ALL DATA USED

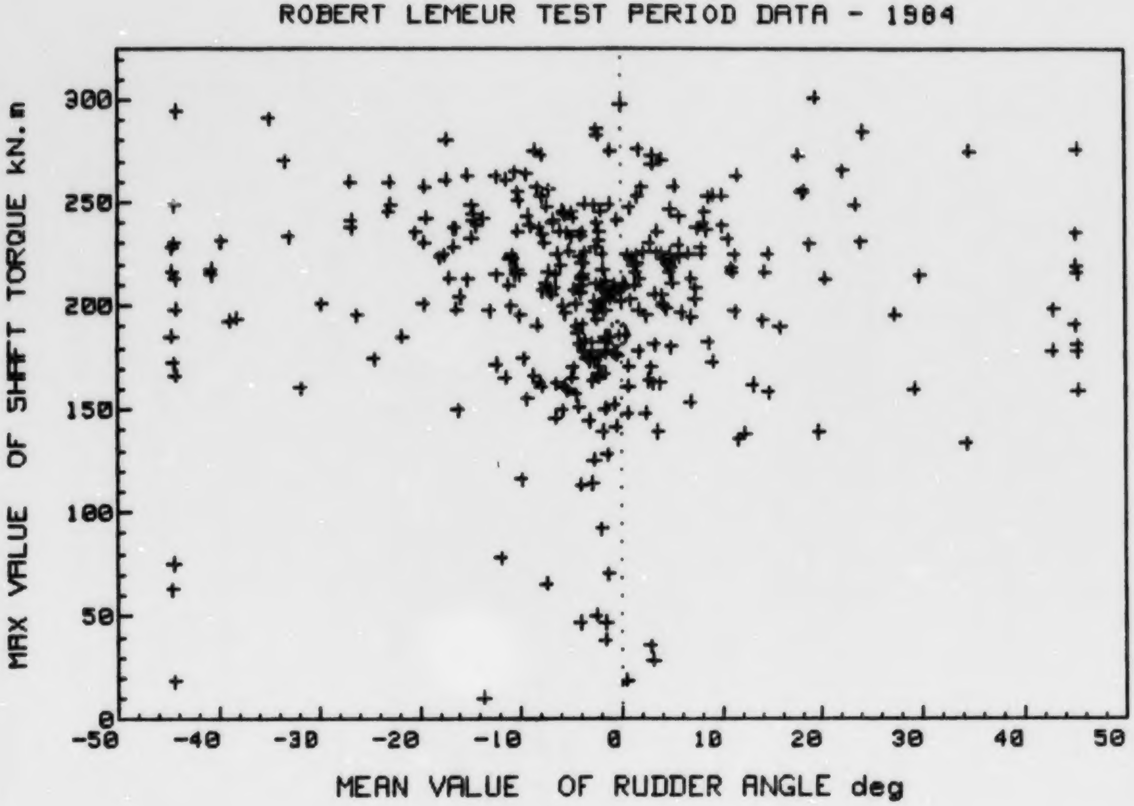
CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: INFLUENCE OF RUDDER ANGLE ON THE MEAN VALUE OF SHAFT TORQUE**
		FIGURE No. 4.5.3-2



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 193

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: INFLUENCE OF RUDDER ANGLE ON THE MINIMUM VALUE OF SHAFT THRUST**
		FIGURE No. 4.5.3-3



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 336

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: INFLUENCE OF RUDDER ANGLE ON THE MAXIMUM VALUE OF SHAFT TORQUE

FIGURE No. 4.5.3-4

iii. The maximum torques are associated with low thrust values.
iv. The maximum torque on one blade was four times the maximum continuous hydrodynamic torque at bollard, if the blade continued to supply hydrodynamic torque, and five times if no significant hydrodynamic torque was developed while milling.

- Shaft Thrust:

i. Ice induced shaft thrust fluctuations are large, in both ahead and astern directions.
ii. The maximum excursions of thrust were 4.6 times the bollard thrust in ahead direction and -1.70 times in astern direction.
iii. When operating in the ice covered waters, the mean level of thrust rose from approximately 250 kN to 550 kN (2.2 times). These numbers require further verification.

4.6 Other Effects

4.6.1 Event Duration

- Blade Impact Duration: Figure 4.6.1-1 shows the histogram of the blade impact durations,[8] in degrees. The following can be observed:

i. Minimum Duration:	7.5°	(0.006s)
ii. Average Duration:	78.7°	(0.063s)
iii. Maximum Duration:	225.0°	(0.179s)
iv. Frequent Duration:	78.7°	(0.063s)

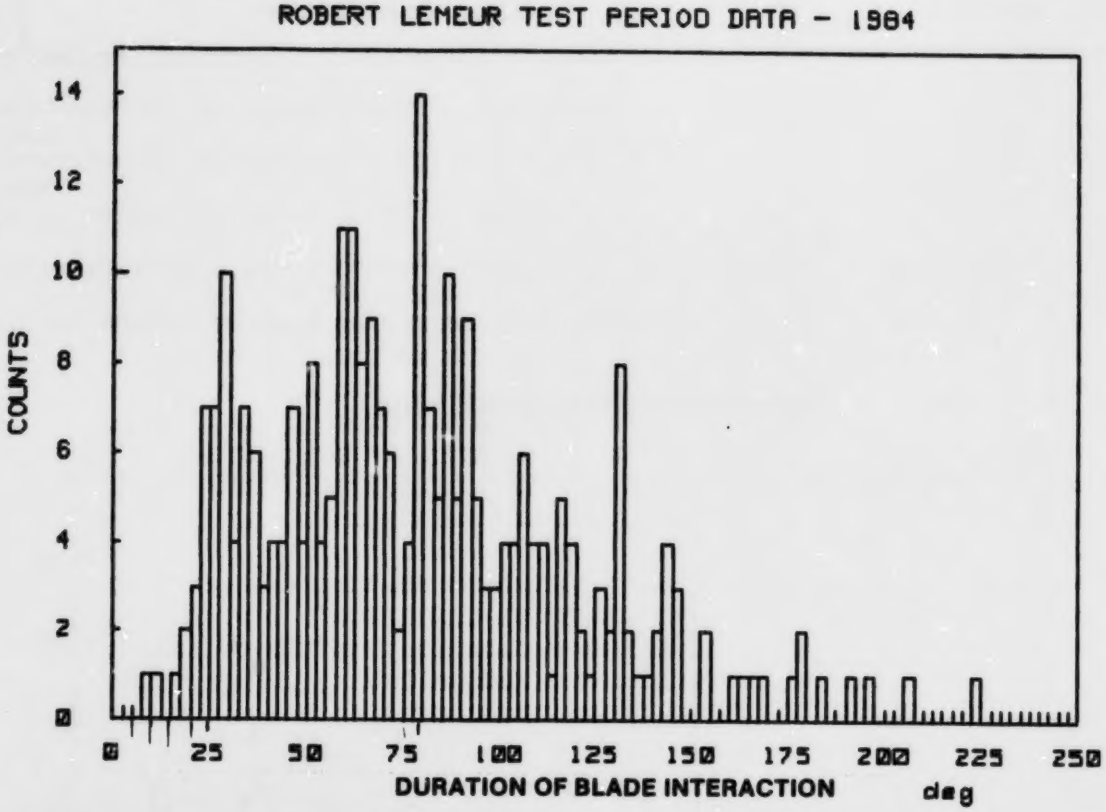
Thus the average duration is of the same order of magnitude as the blade width, i.e. time required to pass the ice block by the blade.

Figure 4.6.1-2 shows the correlation between the magnitude of ice impact force and the blade force event duration. The following observations can be made:

i. The maximum blade forces are associated with short impact durations (less than 100°).

---

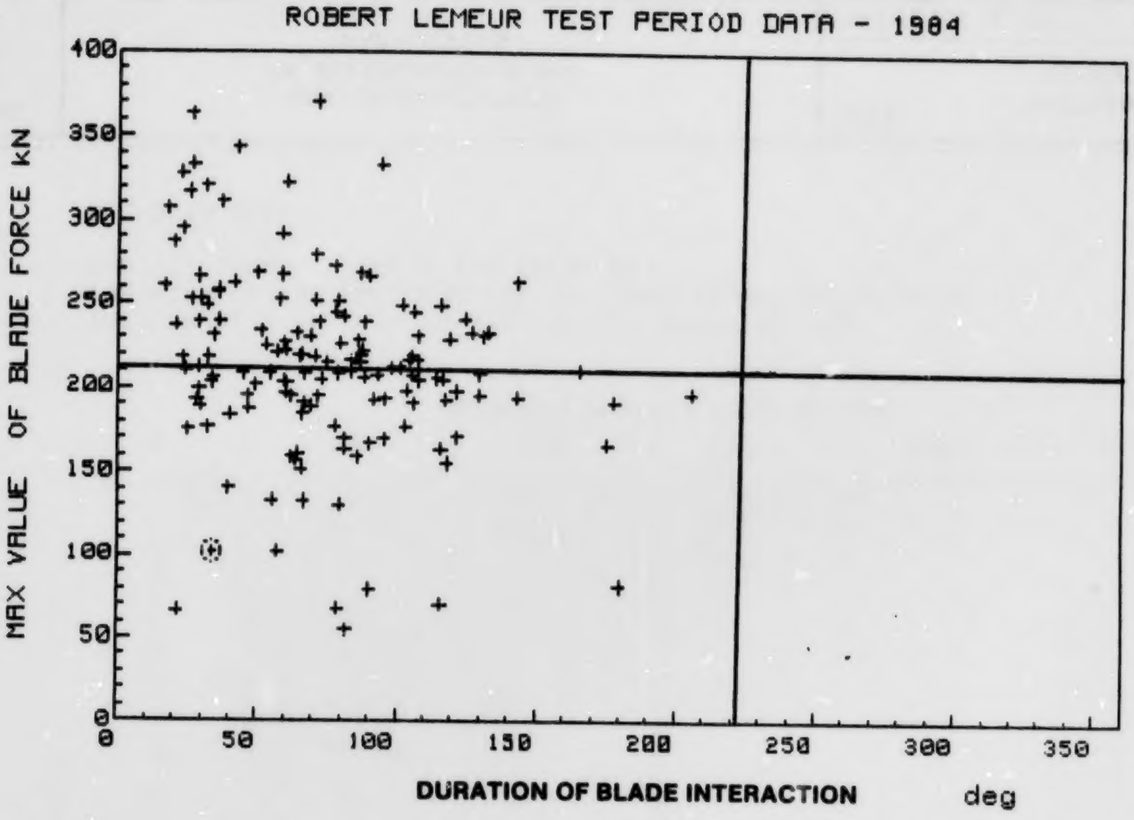
[8] Blade impact duration is defined as the distance, measured in degrees, between the two points where the blade out-of-plane force signal crosses the mean value.



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 282
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:78.712
AND ITS STANDARD DEVIATION IS:40.067

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: HISTOGRAM OF BLADE FORCE DURATIONS
		FIGURE No. 4.6.1-1



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 147

DATA SATISFIED THE FOLLOWING TEST(S)

MEAN VALUE OF SHAFT SPEED > 200 rpm
AND
MEAN VALUE OF PROPELLER PITCH > 0 deg
AND
MEAN VALUE OF SHAFT TORQUE > 140 kN.m

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **MAXIMUM VALUE OF BLADE FORCE IN FUNCTION OF ITS DURATION**
		FIGURE No. 4.6.1-2

ii. Large durations, are associated with low impact forces.
iii. The maximum duration of 225° was due to an impact load with a magnitude of 56% of the maximum load.

This trend indicates that:

i. High impact forces are not necessarily associated with large blocks of ice.
ii. High impact forces may be due to the blade impacting hard ice. Thus hard ice may fail in the brittle mode (shatter) very quickly under the impact.

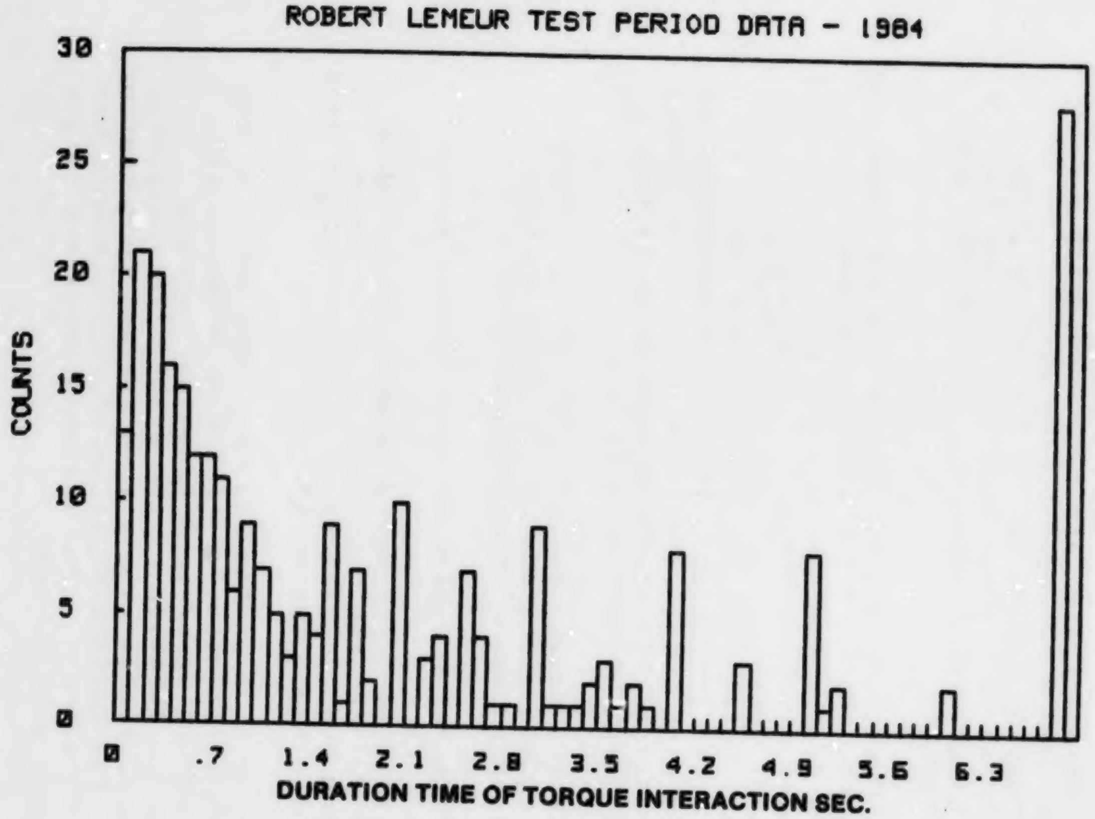
- Torque "Event" Duration: Figure 4.6.1-3 shows the distribution of the shaft torque event durations. The average duration of the shaft torque event is 2 sec. This includes prolonged blockage events. The majority of torque events last less than 0.7 seconds. These event durations are the total time during which ice was interacting with the propeller. These were determined by manually viewing each test. The large group of durations near 7 sec. represents all of the events which lasted longer than the sample length of 6.81 sec.

Figure 4.6.1-4 shows the influence of the torque event duration on the magnitude of the blade maximum force. The following observations can be made:

i. Peak forces occurred at short torque event durations.
ii. There is no correlation between torque event duration and the magnitude of blade force.
iii. Torque event durations of 1 sec and longer lead to high blade impact forces.

Figure 4.6.1-5 shows the Max-Mean excursions of the torque plotted against duration of torque events. It shows that the torque excursions from the mean are proportional to the duration of the event. This suggests that the nature of torque events is different from that of thrust events. The maximum duration of torque events was approximately 2.5 seconds. The maximum torque due to ice interaction lasted 0.55 seconds.

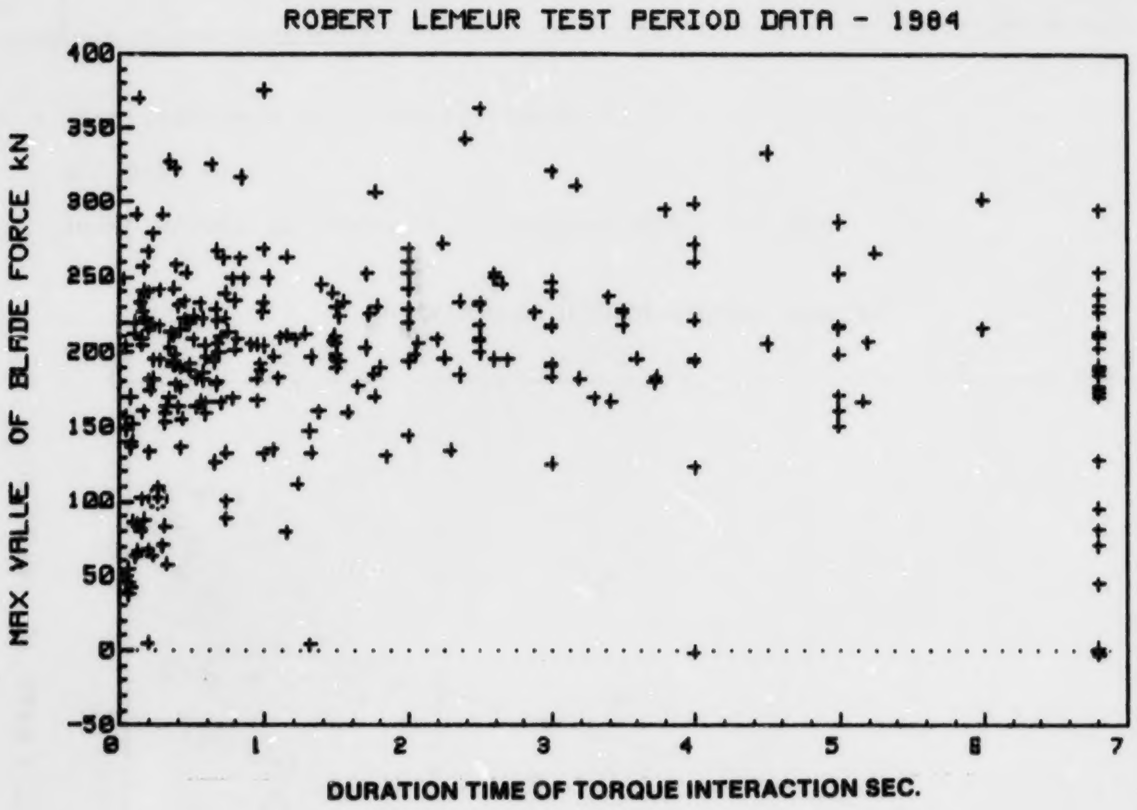
- Thrust "Event" Durations: Figure 4.6.1-6 shows the minimum values of shaft thrusts plotted against the duration of the thrust events. From this plot, it can be concluded that high thrust values are associated with short durations, which is the trend similar to that observed on the blade force.



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 281
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:1.9935
AND ITS STANDARD DEVIATION IS:2.0982

ALL DATA USED

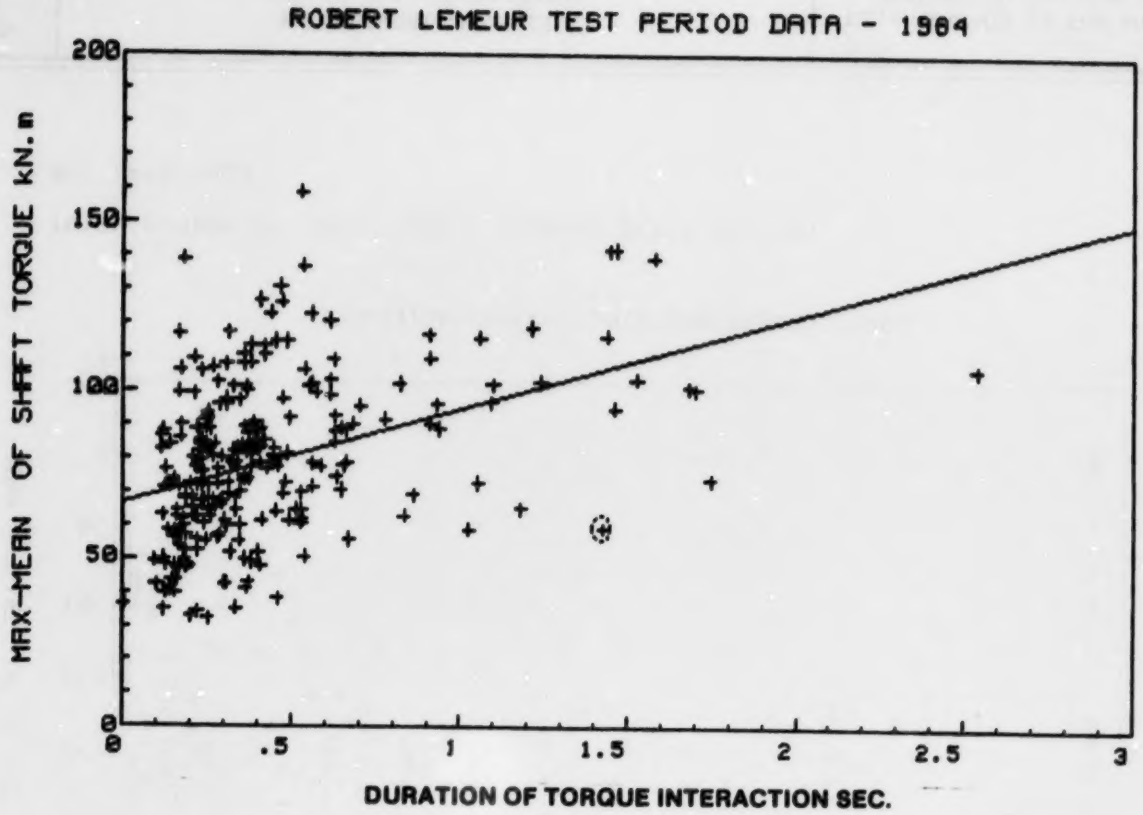
CANMAR CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: HISTOGRAM OF TORQUE EXCURSION TIME
		FIGURE No. 4.6.1-3



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 281

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: DEPENDANCE OF THE MAXIMUM VALUE OF BLADE FORCE ON TORQUE EXCURSION DURATION FIGURE No. 4.6.1-4

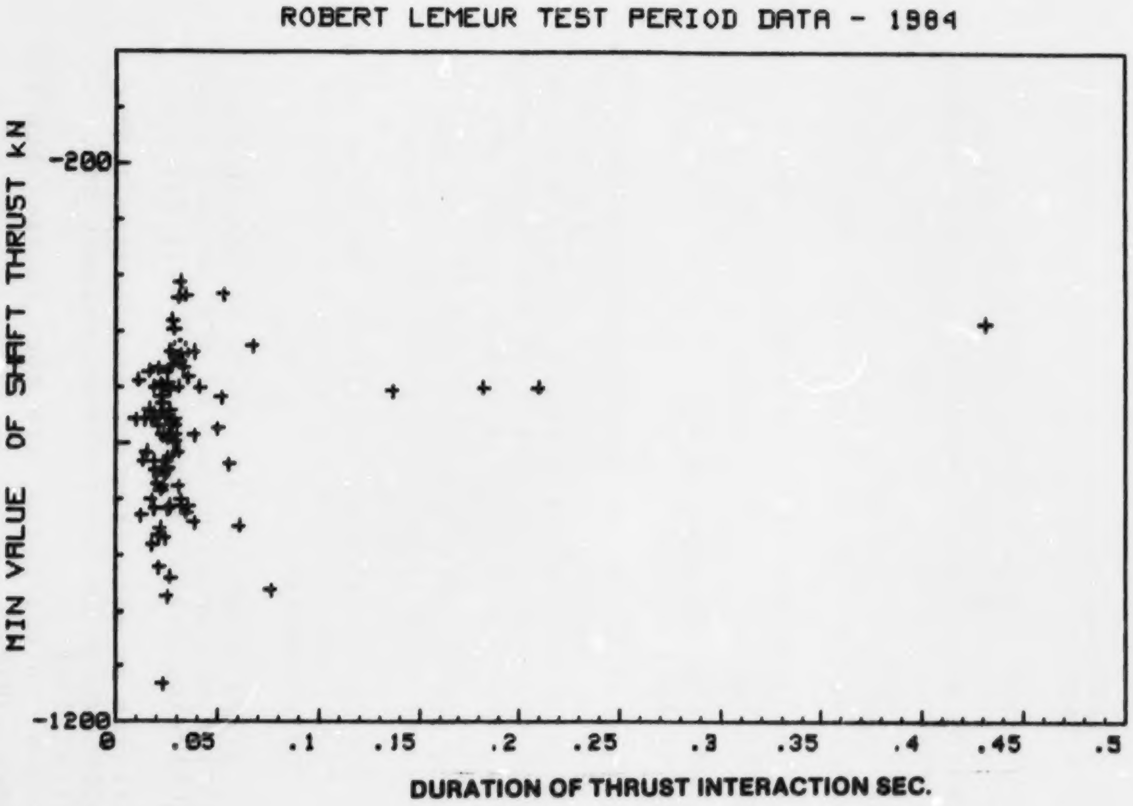


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 257

ALL DATA USED

Y = 27.7766813034 *X + 66.5233400053

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **INFLUENCE OF TORQUE "EVENT" DURATION ON THE MAGNITUDE OF SHAFT TORQUE EXCURSION** **FIGURE No. 4.6.1-5**



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 94

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: INFLUENCE OF THRUST "EVENT" DURATION ON THE MAXIMUM VALUE OF SHAFT THRUST** **FIGURE No. 4.6.1-6**

4.6.2 Investigation of the Blade Position at the Instant of the First Contact between Blade and Ice

Figure 4.6.2-1 shows the statistical distribution of the blade positions at the time of first contact with ice. Two distinct zones are apparent:

$0° < \alpha < 160°$, and;
$160° < \alpha < 360°$

(α is the blade position angle measured counterclockwise from the 12 o'clock position looking forward) where the majority of the first contact between the blade and ice took place. The most frequent interactions were initiated at 45° and 235°, which after adding some 30° for half of the blade width, becomes 75° and 265° of the leading edge position at the first hit.

Little or no interaction takes place at blade angular locations of:

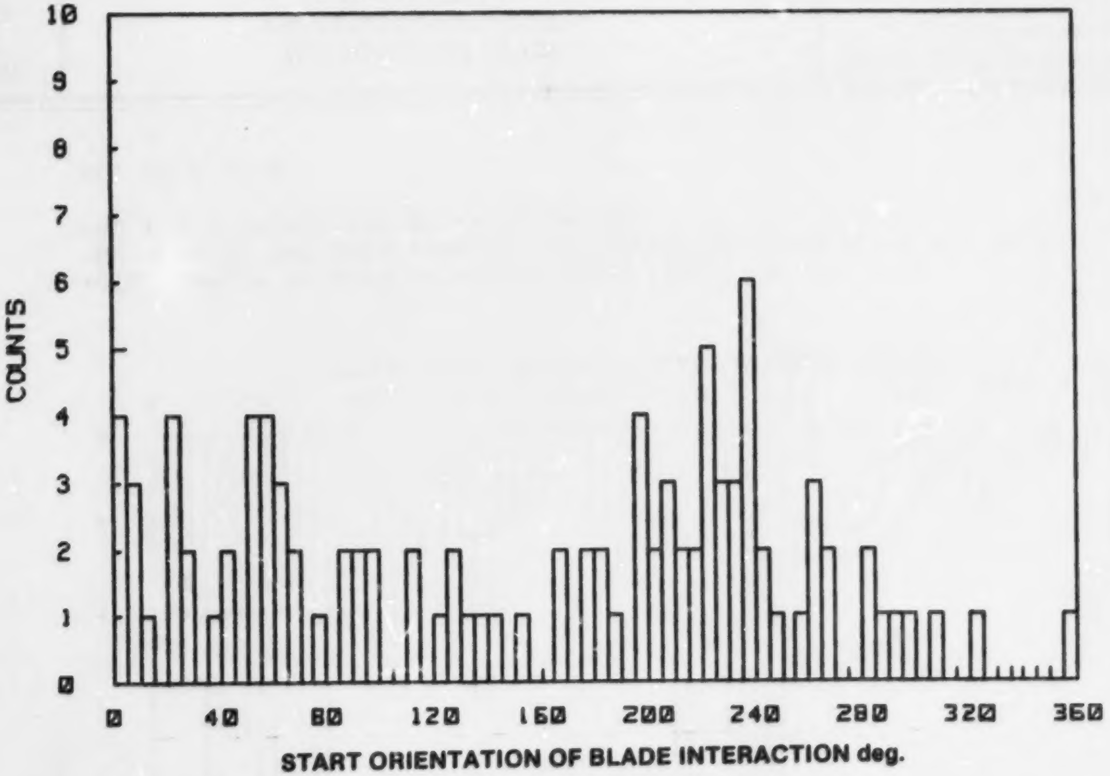
160° (lower skeg shadow), and;
320° (upper skeg shadow).

When these statistics are split into data collected at low velocities of advance (Figure 4.6.2-2) and data collected at high velocities of advance (Figure 4.6.2-3), the influence of the shadowing effect of the skegs becomes more pronounced, especially for the higher speeds of advance ($V > 3m/s$) This is confirming the fact that the flow of ice into the propeller depends largely on the ship induced velocity at high speeds and propeller induced velocity (suction) at low speeds. At low speeds, ice is being sucked from many different locations, while at high speeds, water flow "brings" the ice along the bottom of the ship into the propellers.

Figure 4.6.2-4 shows the influence of the initial hit blade position on the magnitude of the maximum blade force. The following can be deduced from this figure:

- Interaction is more frequent in the zone $160° < \alpha < 360°$, which is the outboard segment of propeller disk.
- "Outboard "interactions, are more severe then the "inboard" ones.
- Although little interaction takes place in the zone $100° < \alpha < 200°$, the level of ice impact forces is high.

ROBERT LEMEUR TEST PERIOD DATA - 1984

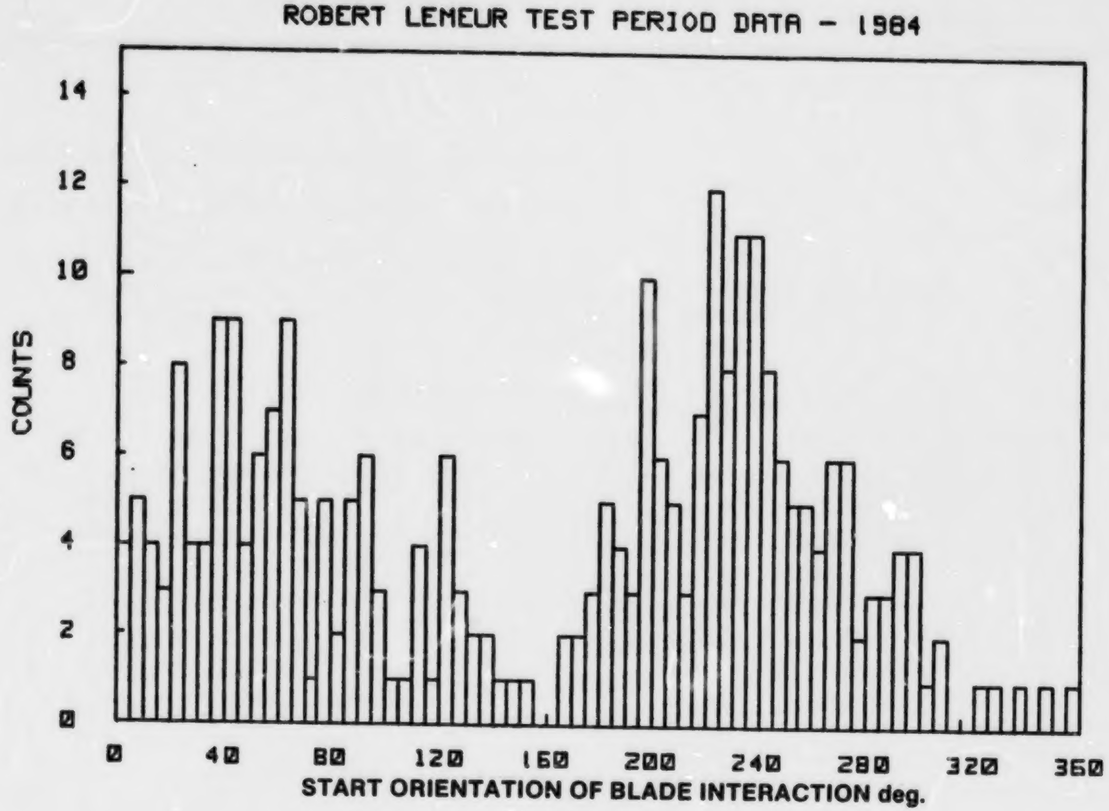


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 100
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:154.54
AND ITS STANDARD DEVIATION IS:94.658

DATA SATISFIED THE FOLLOWING TEST(S)

MEAN VALUE OF SHIP SPEED < 3 m/s

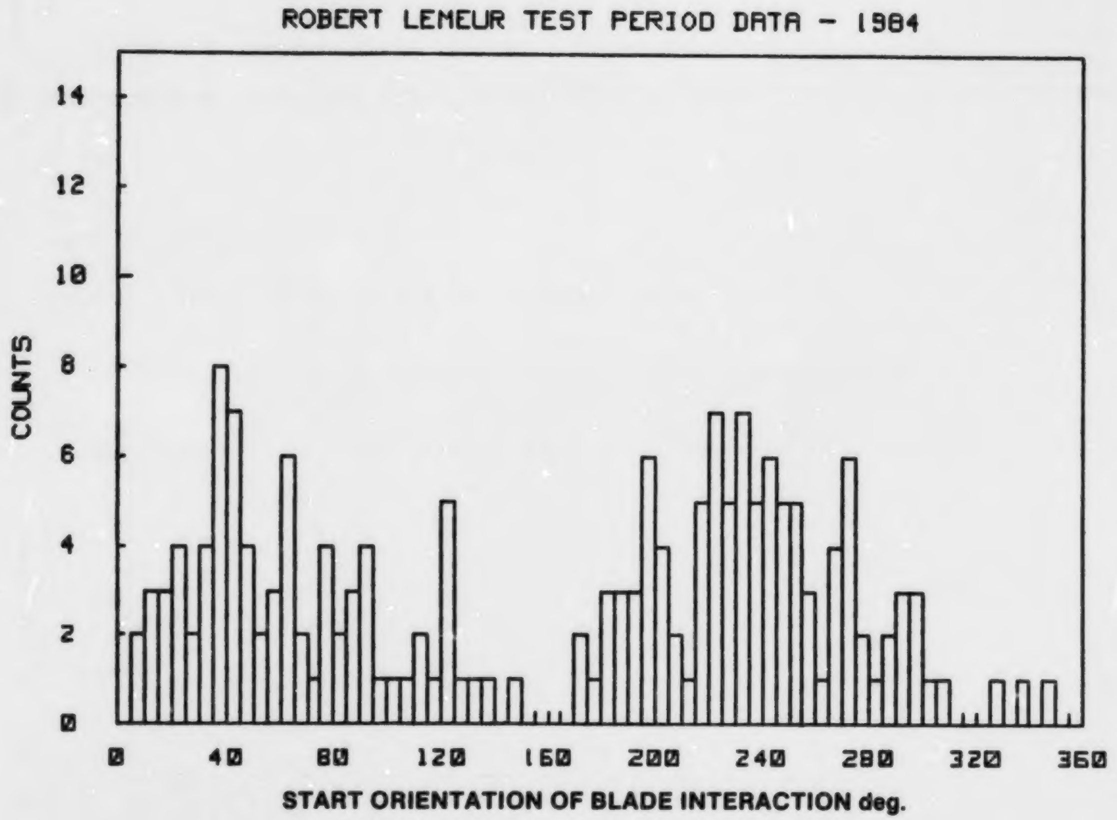
CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: STATISTICS OF THE ANGULAR POSITIONS OF THE BLADE AT THE INSTANT OF CONTACTING ICE BLOCKS FIGURE No. 4.6.2-1



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 282
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:159.01
AND ITS STANDARD DEVIATION IS:94.998

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: STATISTICS OF THE ANGULAR POSITION OF THE BLADE AT THE INSTANT OF CONTACTING ICE BLOCKS, V SHIP < 3 m/s FIGURE No. 4.6.2-2



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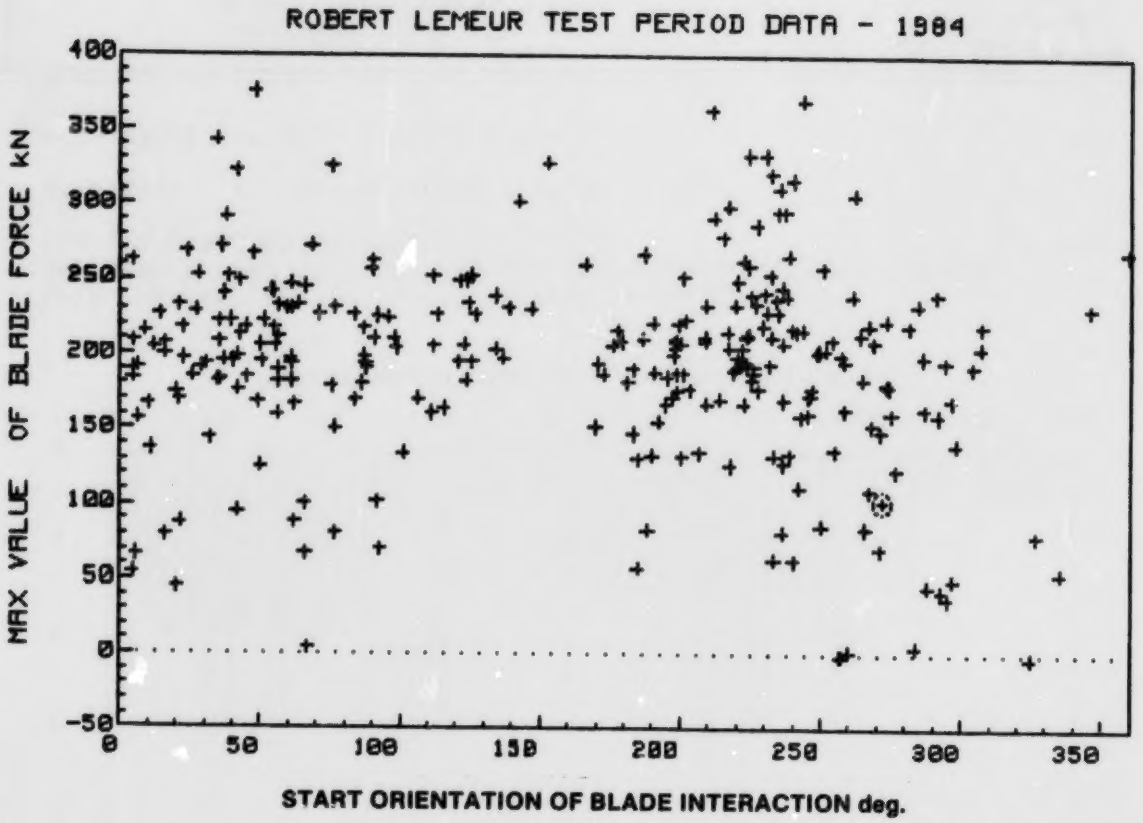
TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 179
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:161.06
AND ITS STANDARD DEVIATION IS:95.216

DATA SATISFIED THE FOLLOWING TEST(S)

MEAN VALUE  OF SHIP SPEED > 3 m/s
```

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: STATISTICS OF THE ANGULAR POSITION OF THE BLADE AT THE INSTANT OF CONTACTING ICE BLOCKS V SHIP > 3 m/s** **FIGURE No. 4.6.2-3**



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 282

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: INFLUENCE OF THE ANGULAR POSITION OF THE BLADE-ICE CONTACT ON THE MAXIMUM VALUE OF BLADE FORCE**
		FIGURE No. 4.6.2-4

- The peak impact force occurred at approximately 50° orientation angle, which translates into 80° leading edge position.

Maximum values of blade forces occur at approximately 50° and 240°, which is due to the fact that ice blocks are, most likely, aligned vertically by the skeg in the nozzle.

Figure 4.6.2-5 shows the distribution of the blade impact positions for short duration impacts (durations less than 90°). The symmetry of the two zones is clearly depicted. This shows that the small ice blocks are distributed uniformly to the port and starboard of the propeller center plane.

Figure 4.6.2-6 shows the distribution of the propeller angular positions at the instant of the occurrence of the peak of blade force. As before, there are two distinct groups of positions:

$0° < \alpha < 180°$, and;
$220 < \alpha < 360°$.

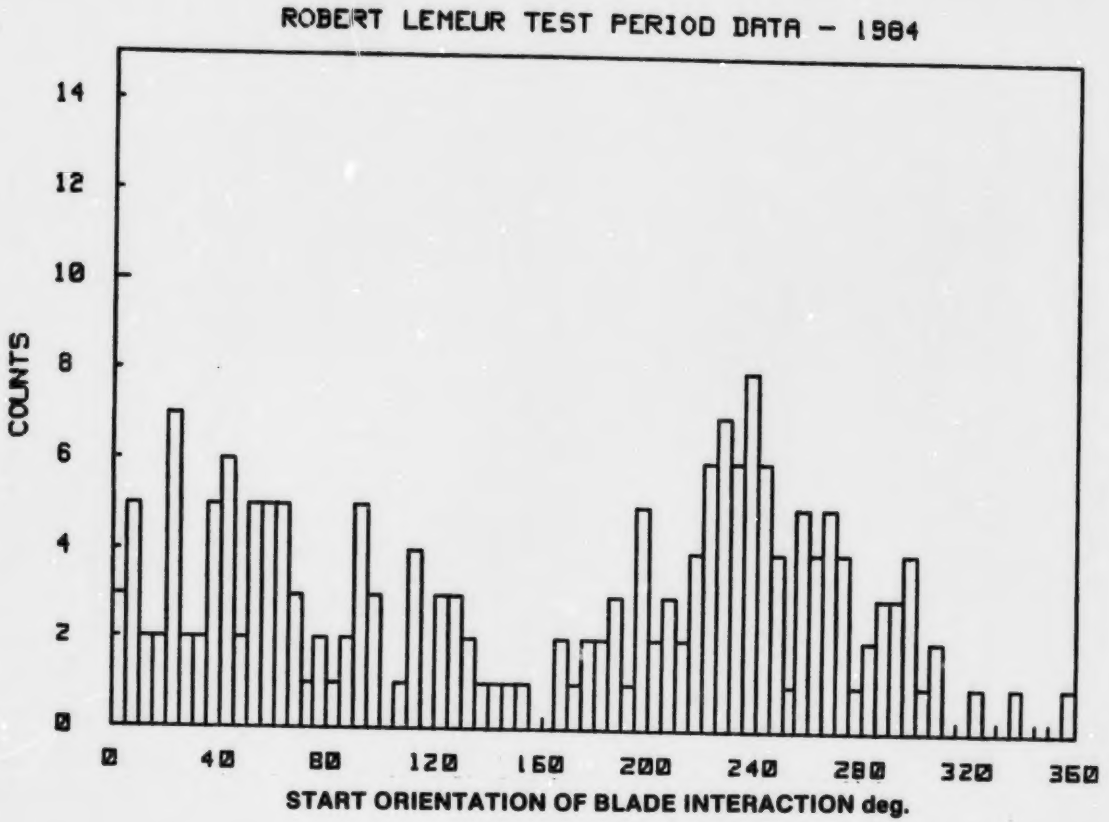
The average positions for these two groups are estimated to be at 100° and 280°, respectively. These positions suggest a shift of approximately 45° between the position of the first contact and that of the peak force. Adding 30° for the leading edge position, we will arrive at 130° and 310° as the average angular positions of the force at its peak. These positions may influence the design of the shafting system. The drift of 45° between the initial and peak position of the blade corresponds to approximately 2/3 of the blade width.

There are two most likely positions of the blade at the peak force instant: 150° and 320° spaced apart by 170°.

Note also that the mean positions of the blade at peak force are spaced 180° Such a spacing shows the symmetry about the vertical skeg-line.

4.6.3 Assessment of the Displacements of the Blade under the Load

- Static Case: A blade can be considered as a tapered beam having nearly-linear distribution of the sectional inertia along its length. Denoting distance along the blade-beam as x having its origin at the blade tip, we will have:

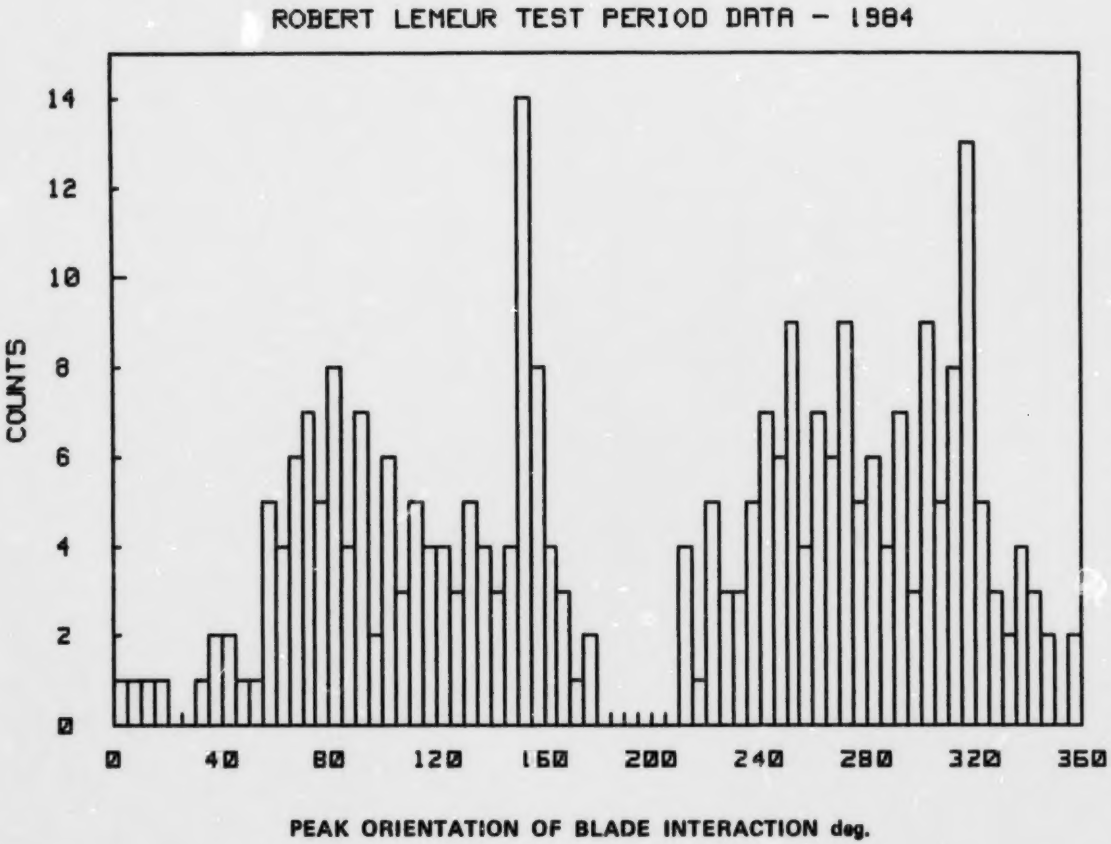


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 187
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:160.70
AND ITS STANDARD DEVIATION IS:97.535

DATA SATISFIED THE FOLLOWING TEST(S)

DURATION OF BLADE START PEAK & DURATION < 90 deg

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: STATISTICS OF ANGULAR POSITIONS OF BLADE-ICE CONTACT FOR SHORT BLADE-ICE IMPACTS FIGURE No. 4.6.2-5



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 282
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:199.94
AND ITS STANDARD DEVIATION IS:95.073

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: DISTRIBUTION OF PROPELLER ANGULAR POSITION AT THE INSTANT OF THE OCCURRENCE OF THE PEAK BLADE FORCES FIGURE No. 4.6.2-6

$I(x) = I_o (1 + (\kappa - 1) * x / L)$

Where I_o is the inertia of the cross section at the $x = o$. L is the length of the beam and $\kappa = I_R/I_o$ denotes the ratio of the inertia at blade root to that at the origin of coordinate system.

The equation governing the beam response is:

$EI(x) * \ddot{y} = Fx.$

the solution of which is:

$y(o) = FL^3/EI_0 * [1/2(\kappa-1)-1/(\kappa-1)^2+(\ln \kappa)/(\kappa - 1)^3)]$

$= FL^3/EI_0)* C_1$

$\dot{y}(o) = FL^2/EI_0 * [(\ln \kappa) / (\kappa - 1) - 1 / (\kappa - 1)]$

$= (FL^2/EI_0)* C_2$

Tabulation of the values C_1 and C_2 is given below:

κ	1	1.1	1.2	1.5	1.8	2.0	2.5	3	4	6	18
C_1	0.3	0.31	0.29	0.24	0.21	0.19	0.16	0.14	0.10	0.07	0.03
C_2	0.5	0.47	0.44	0.38	0.33	0.3	0.26	0.22	0.18	0.16	0.10

Note that for $\kappa = 1$ coefficients C_1. and C_2 correspond to the coefficients given in the textbooks for the straight (non-tapered) beams.

For an ice force applied at $r/R = 0.7$, taking the origin of the coordinate system at $r/R = 0.7$ gives:

$I_o = 6.4 * 10^{-6}\ m^4$

$I_R = 114 * 10^{-6}\ m^4$

$\kappa = I_R/I_o = 18$

$r/R = 0.82 + 1.5 * 0.375 / 1.5 = 0.92$

$y\ (r/R = 0.92) = 0.03\ FL^3/EI_o$

$\dot{y}\ (r/R = 0.92) = 0.10\ FL^2 / EI_o$

Substituting for I_o. $L = 0.82$ m, $E = 1.3 * 10^{11}$ Pa, we will obtain:

$y\ (0.92) = 1.8 * 10^{-8}$

$\dot{y}\ (0.92) = 8.0 * 10^{-8}$

Total deflection at the tip is:

$Y_{tip} = y\ (0.92) + (1.04 - 0.82) * \dot{y}\ (0.92) = 3.6 * 10^{-8} * F$

For the force of 370 kN, the tip deflection is:

$y_{tip} = 0.013$ m

Under the dynamic conditions, this value may be higher due to the dynamic magnification factor. However, since water may dampen the vibrations and also provides the "elastic foundation" for the blade, these two effects may cancel each other.

- Dynamic Case: Assume that the blade vibrates with the frequency of 40 Hz about its neutral position (free vibrations) with an amplitude $y_{tip} = 0.013$ m. Equation of the motion of the tip of the blade is:

$y_{tip} = y_o \sin(\omega t)$, where $\omega = 2\pi * 40$ Hz

Then the maximum velocity of the vibration is:

$\dot{y}_{max} = y_o \omega = 0.013 * 2\pi * 40 = 3.3$ m/s

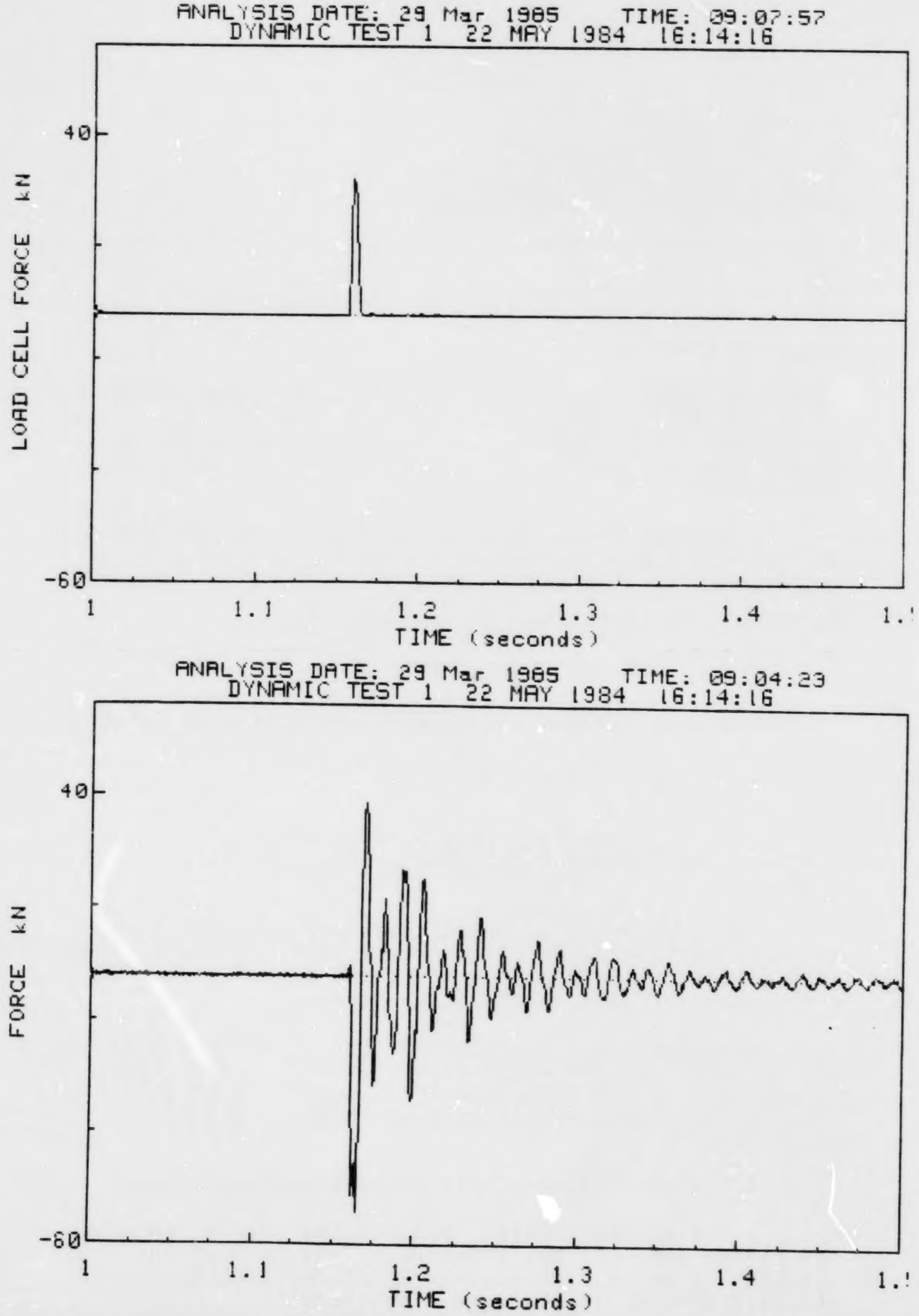
This velocity is of the same order of magnitude as the water velocity in the direction perpendicular to the blade surface.

When the blade is bent forward by ice, its "net" velocity against water becomes very small, and the blade looses most of its hydrodynamic load, which is proportional to the net velocity squared.

When the blade is released (ice is cut through) its net velocity against water nearly doubles, which leads to quadrupling of the hydrodynamic load. Thus the return of the blade to its neutral position is slowed down considerably.

4.6.4 Assessment of the Blade Free Vibrations

- Vibrations in Air: Dynamic Test No. 1, shown on the Figure 4.6.4-1, has a frequency spectrum of the blade response shown on Figure 4.6.4-2. Three frequencies are strongly present in the free vibrations:



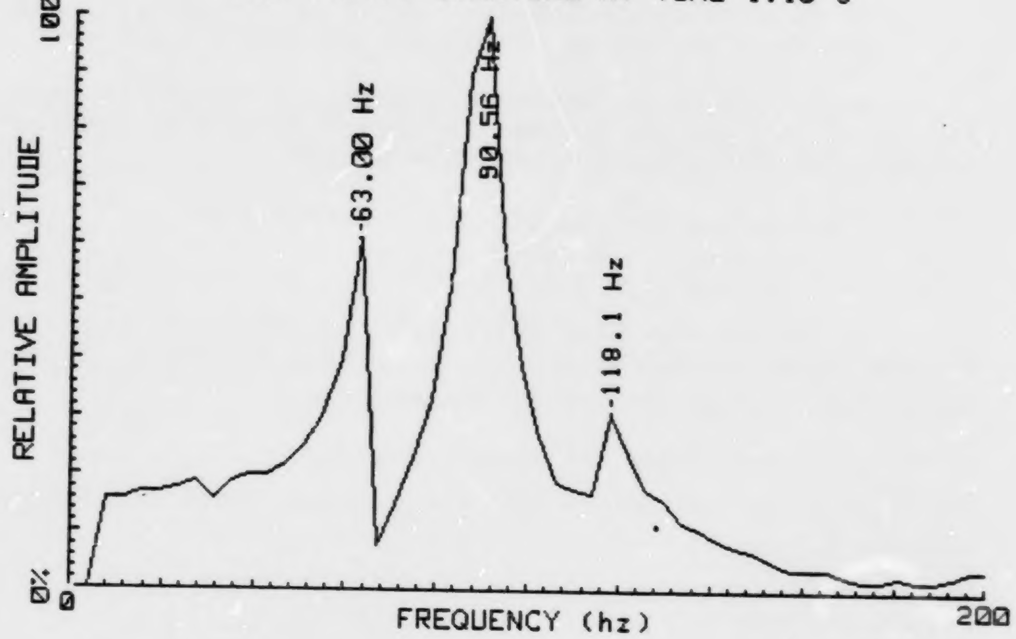
CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

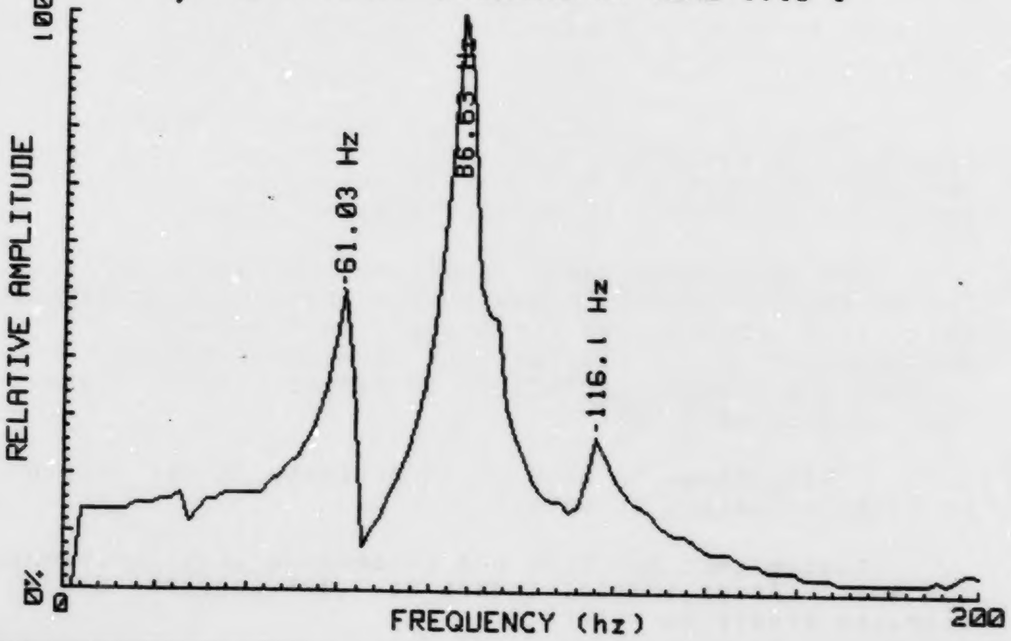
TITLE:
DYNAMIC TEST OF THE BLADE IN AIR

FIGURE No. 4.6.4-1

DYNAMIC TEST 1
FFT of FORCE
MAXIMUM AMPLITUDE = 6.68E+00 kN
512 POINTS STARTING AT TIME 1.16 s



DYNAMIC TEST 1
FFT of FORCE
MAXIMUM AMPLITUDE = 3.85E+00 kN
1024 POINTS STARTING AT TIME 1.16 s



CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: FREQUENCY SPECTRUM OF DYNAMIC TEST #1
		FIGURE No. 4.6.4-2

90 Hz with corresponding period of 0.0111 sec;
60 Hz with corresponding period of 0.0167 sec, and;
120 Hz with corresponding period of 0.0083 sec.

While 120 Hz is the second harmonic of 60 Hz, the first (60 Hz) and the second (90 Hz) frequencies combine to form the "beat" frequency with period:

$$T = \frac{2\pi}{\omega_1 - \omega_2} = \frac{2\pi}{2\pi\,(90 - 60)} = 0.0333 \text{ sec}$$

To assess the damping factor for the beat, the following calculations are made. Taking X_2 and X_1 as the successive values of the beat amplitude:

$X_2/X_1 = 0.56$ (From the figure 4.6.4-2)
$\ln (X_2/X_1) = \mu T$, where μT is the logarithmic decrement.
Solving for μ:
$\mu = 17.4$,

Pseudo frequency $p = 2\pi/T = 188.5 \text{ sec}^{-1}$
Frequency is:
$(p^2 + \mu^2)^{1/2} = (189^2 + 17.4^2)^{1/2} = 189.3 \text{ sec}^{-1}$
Damping ratio is then:
$\xi = 17.4/189.5 = 0.092$

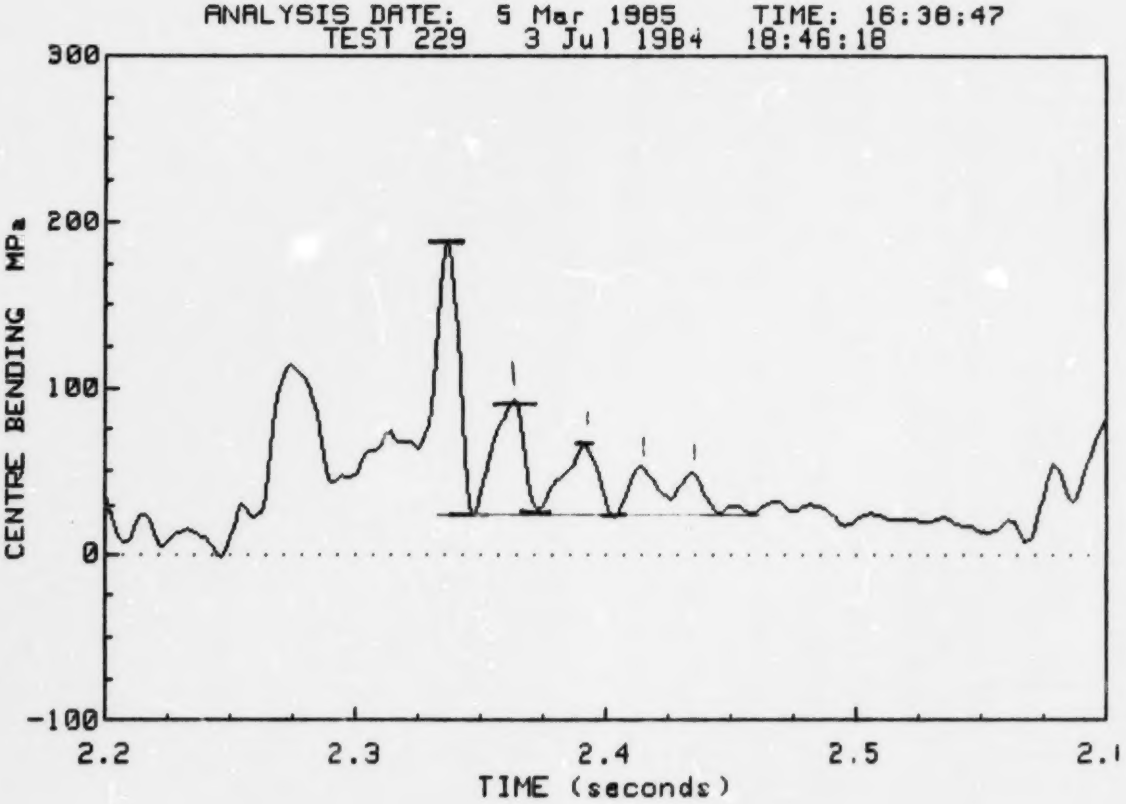
Since the predominant frequency is 90 Hz, we will assess the dynamic magnification factor from the reference No. 4.6.4-1. To do this, the period of the excitation force is found from Figure 4.6.4-2 to be $T_{excit} = 0.0083$ sec (120 Hz).

The ratio of excitation frequency to response frequency is therefore 1.33 to 1. Entering Figure 16 of Reference No. 4.6.4-1 will obtain the dynamic magnification factor to be approximately 1.6.

The measured dynamic magnification factor was 1.7. The small discrepancy is due to the large damping factor calculated for the beat frequency. As the lower amplitudes of force fluctuations have lower damping factor, its dynamic magnification factor will be higher that calculated above.

- Vibrations in Water: An estimate of the damping of blade vibration in water:

Taking test No. 229, centre bending signal, (Figure 4.6.4-3). After initial impact at 2.325 sec, the blade vibrates freely in water.



CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **FREE VIBRATIONS OF BLADE IN WATER**

FIGURE No. 4.6.4-3

The following observations can be made:

- High amplitude initial bending is dampened very quickly.
- Low amplitude vibrations are dampened slowly.
- The minimum value of the centre bending signal remains constant during the forced vibration period.
- The average value of the signal decreases during the forced vibration period.

We will calculate large amplitude damping coefficient first. The ratio of two consecutive full amplitudes (Max-Min) is (from Figure 4.6.4-3):

$X_2/X_1 = 0.2$ and their pseudo-period is $T = 0.025$ sec
and pseudo-frequency is $p = 251$

$\ln(1/2 * X_2/X_1) = \mu T$, from which will obtain $\mu = 64.37$.

Its logarithmic decrement is:

$\rho = \mu T = 64.37 * 0.025 = 1.61$, and the frequency is:

$\omega = (p^2 + \mu^2)^{1/2} = (241^2 + 64.37^2)^{1/2} = 259$,
$\zeta = 64.37/259 = 0.25$

Small amplitude damping can be calculated using similar procedure. From Figure 4.6.4-3, the following numbers are obtained.

$(1/2)(X_2/X_1) = 0.29$, $T = 0.033$, $p = 190$

$\mu = 37$, $\zeta = 1.23$
$\omega_o = 193$
$\zeta = 37/193 = 0.19$

Thus one can conclude that: The heavy damping is present for both large and small amplitude vibration of the blade in water. The damping ratio is 0.25 for large amplitude and 0.19 for small amplitude vibration. The frequency of free vibration in water is approximately 40 Hz.

- An Estimate of the Added Mass: Frequency of free vibration in air is 90 Hz. Calculated frequency of for vibration in water is approximately 40 Hz. The definition of the circular frequency of vibration of the single degree of freedom system is:

$$\omega = (k/m)^{1/2}$$

where K is the stiffness of the spring, and m the particle mass.

From the above, the following ratio can be derived:

$\omega_{air}/\omega_{water} = (m_{water}/m_{air})^{1/2} = (1 + \lambda)^{1/2}$ where λ is the added mass coefficient.

Substituting for ω_{air} and ω_{water}, the added mass coefficient is estimated to be:

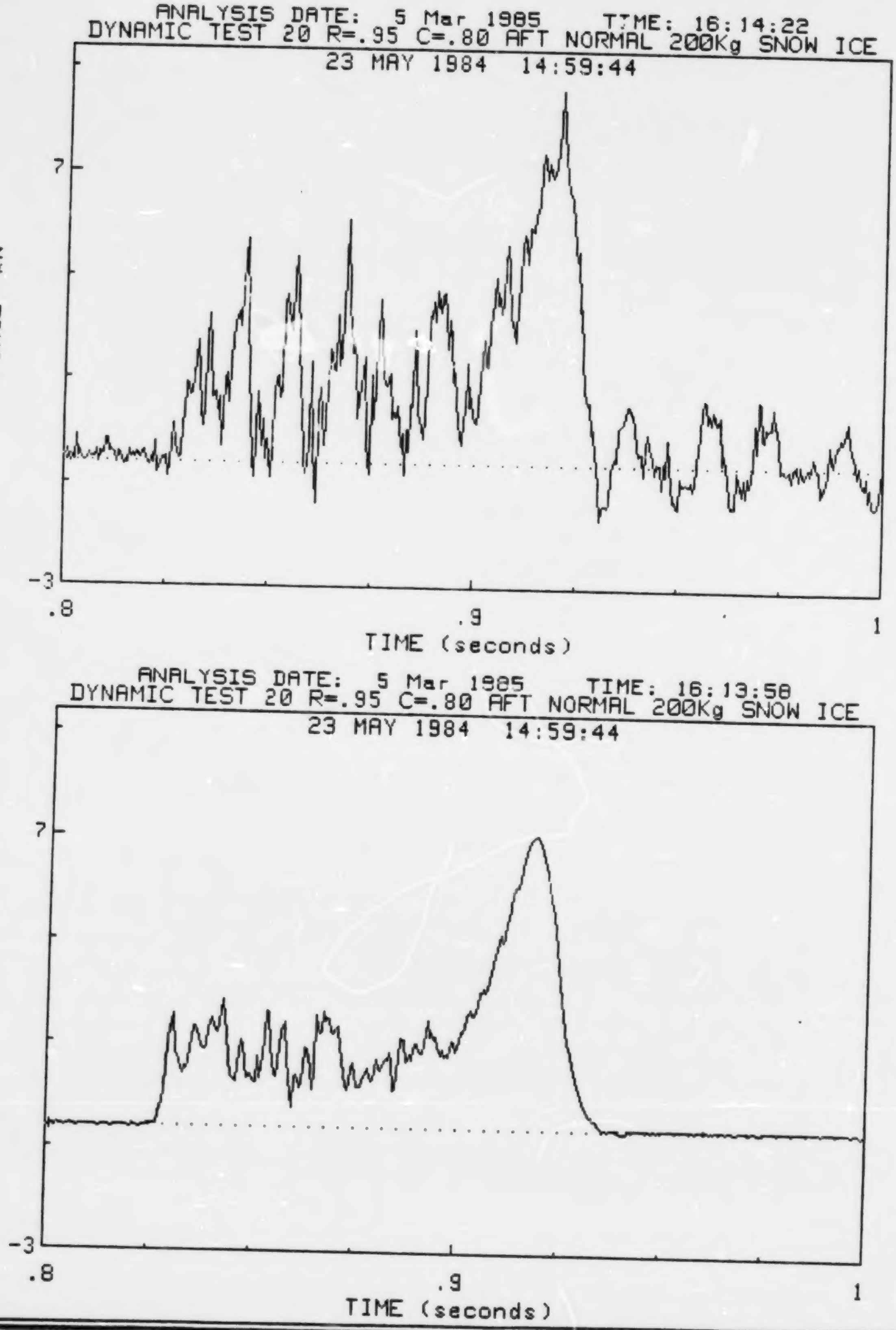
$$\lambda = (90/40)^2 - 1 = 4$$

thus the added mass is 4 times the mass of the blade.

4.6.5 Assessment of the Dynamic Magnification of Blade Response to Ice Impact

It has been shown that the dynamic magnification of the blade response to a very short impulse is 1.7. It is well known that the dynamic magnification factor depends on the ratio of the forcing frequency to natural frequency of the system. To estimate this ratio, the following calculations have been performed.

Dynamic test number 20 was performed in order to assess the dynamic response of the blade under simulated ice crushing conditions. Figure 4.6.5-1 shows the time history of the load cell response and the time history of the blade response. From this figure, the dynamic magnification factor is:



CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **TIME HISTORY OF THE DYNAMIC TEST #20**
		FIGURE No. 4.6.5-1

Dynamic Magnification Factor = Blade Force/Load Cell Force = 1.28

A check of the value can be performed using the Fast Fourier Transform (FFT) technique of the blade response during ice crushing (Figure 4.6.5-2) and during free vibrations (Figure 4.6.5-3). Comparing these figures, it can be concluded that the forcing frequencies were 23.6 Hz, and that the predominant response frequencies were 65 Hz and 92 Hz. Thus, the ratios of the forcing frequency to the response frequency are: 0.36 and 0.26. Dynamic magnification factors for these ratios are, (from reference 4.6.5-1), 1.2 and 1.10, respectively. Therefore, the dynamic magnification factor of 1.28 is a reasonable value.

During the actual interaction between the blade and ice, the ratio of forcing frequency to the blade response frequency can be assessed as follows: Free vibrations of the blade in water have a period of 1/40 Hz = 0.025 sec. Damping factors for these vibrations have been assessed to be 0.09 and 0.25 for low amplitude and high amplitude vibrations, respectively.

Paragraph 4.6.1 gives the following values of impact durations (note that these are really the blade response durations):

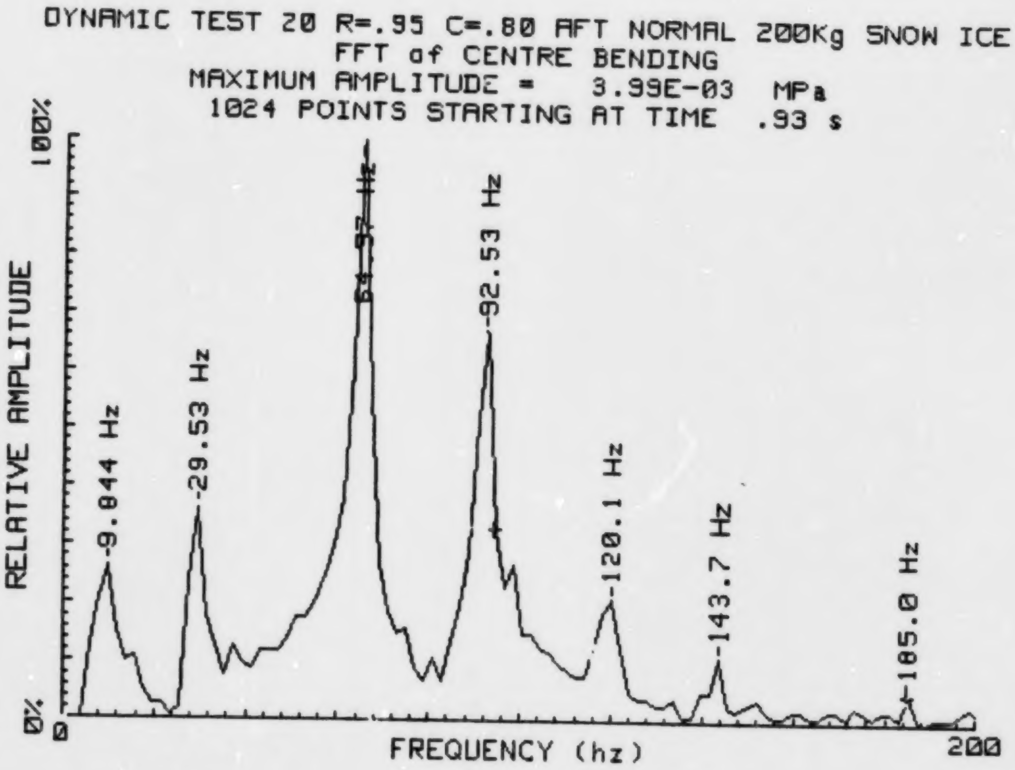
- Minimum Duration	0.006 sec
- Average	0.063 sec
- Maximum	0.179 sec
- Most Frequent	0.063 sec

The time to pass a fixed point in space (ice block) by a blade width at $r/R = 0.7$ is 0.043 sec. The actual load duration is thought to be less than that value. Thus, the ratio of the forcing function period to the response period is:

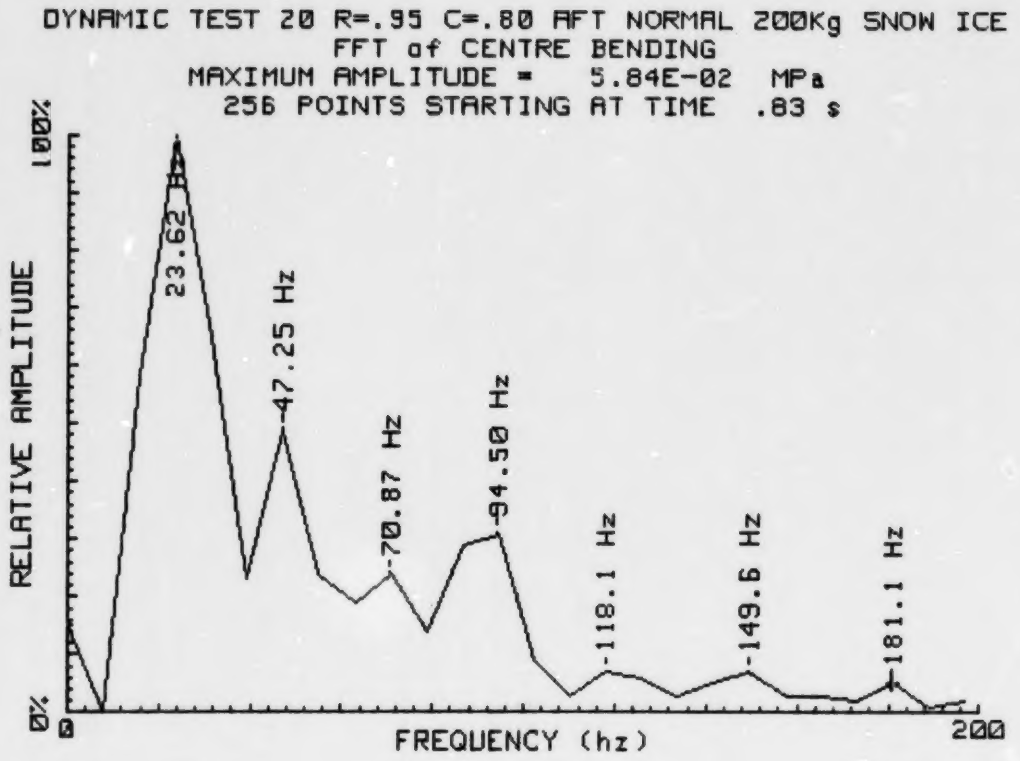
$\zeta < 0.043/0.025$ ie. $\zeta < 1.72$

If one assumes that the forcing function period is approximately 1/2 of the response period then the following table can be compiled:

Impact Force	Duration	Impact Response Duration	Dynamic Magnification Factor
Minimum Duration	0.003 sec.	0.12	0.1
Average Duration	0.032 sec.	1.28	1.3
Maximum Duration	0.095 sec.	3.60	1.2
Most Frequent "	0.032 sec.	1.28	1.3



CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: FFT OF THE CENTRE BENDING FOR THE DYNAMIC TEST #20
		FIGURE No. 4.6.5-2



CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **FFT OF THE CENTRE BENDING, DYNAMIC TEST #20, FREE VIBRATIONS**
		FIGURE No. 4.6.5-3

It should be noted that short impacts produce high loads (see paragraph 4.6.1). This may be due to the dynamic magnification factor. Only a detailed analysis of each individual impact can provide an answer as to the nature of the forcing function. An analysis of the highest blade bending moment event (No. 336) was performed in order to assess the influence of dynamic magnification.

The time history of the centre bending signal is shown on Figure 4.6.5-4. The duration of the signal was approximately 0.01 seconds. An FFT of the whole event is shown on the Figure 4.6.5-5 and FFT of the post impulse blade vibrations is given in the Figure 4.5.5-6. Comparison of these two figures shows that the forcing frequency was at 8 Hz. The blade responded at 6 Hz, that is the ratio of forcing to free vibration period was 0.75. There is only weak presence of the blade free vibration frequency at 42 Hz. The low frequency values are suspect, however, as they reflect the long period fluctuations of the signal dependent on the choice of the initial and terminal time instant.

The ratio of the duration of the impact (1/2 of the duration of the signal) to that of the blade free vibration period is 1/2 * 0.01/0.025 = 0.2. For this ratio, the dynamic magnification factors is (Reference 4.6.5-1) 0.7. It means that the actual force causing the blade bending moment signal was 1.4 times larger than that predicted from the static analysis.

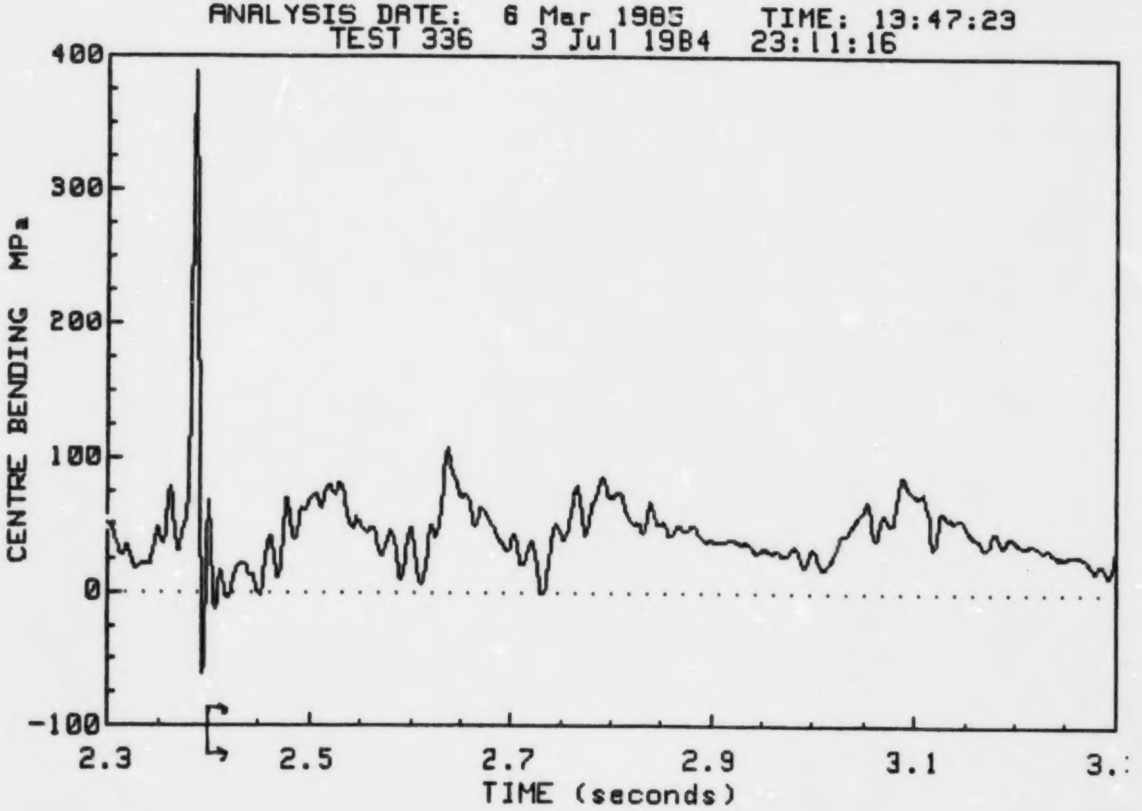
4.6.6 Blade Bending Moment

The histogram of the maximums of the blade bending moments (BBM) is shown on Figure 4.6.6-1. Two groups are apparent: One, centered about 17.6 kN*m reflects the hydrodynamic load blade bending (0 type of interaction, see Chapter 4.2), and; The other, centered about 164 kN*m is due to ice induced loads.

The maximum value recorded during the tests was 310 kN*m, which was 5.2 times higher than the maximum blade bending moment in open water conditions.

The average maximum blade bending moment during all of the tests was 148.24 kN*m, which is approximately 5 times higher than the average of the maximums in open water conditions.

The influence of the type of the event on the magnitude of the maximum blade bending moment is shown on Figure 4.6.6-2. From this figure, it can be concluded that while the mean of the maximums does not vary from one

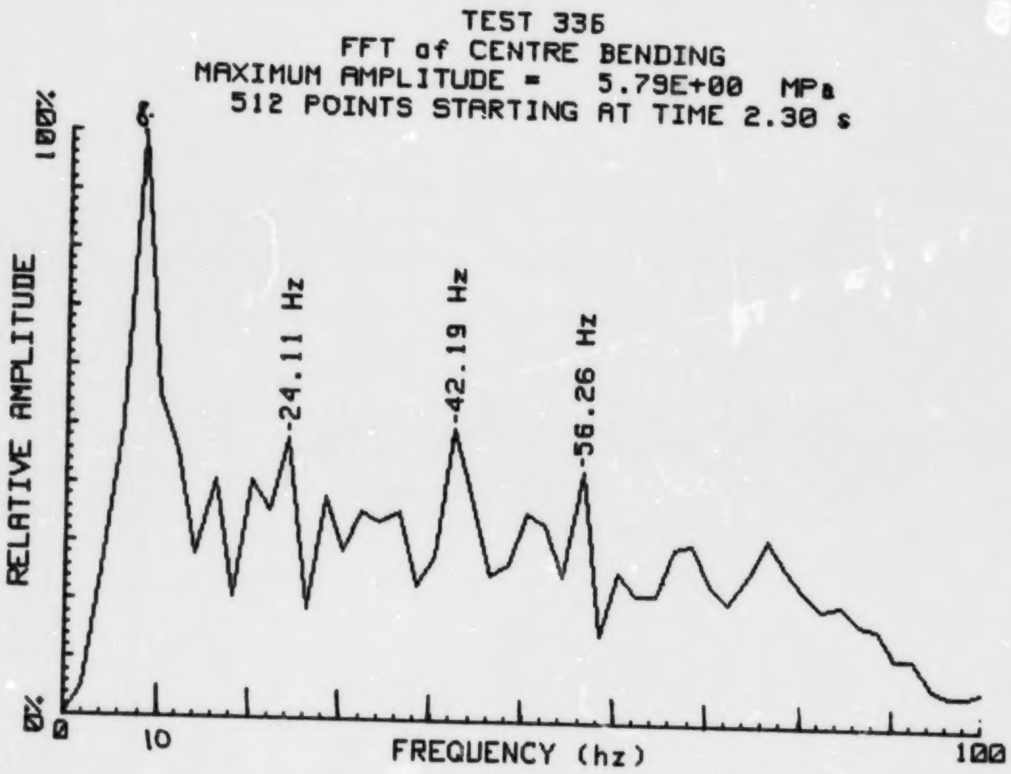


CANADIAN MARINE DRILLING LIMITED

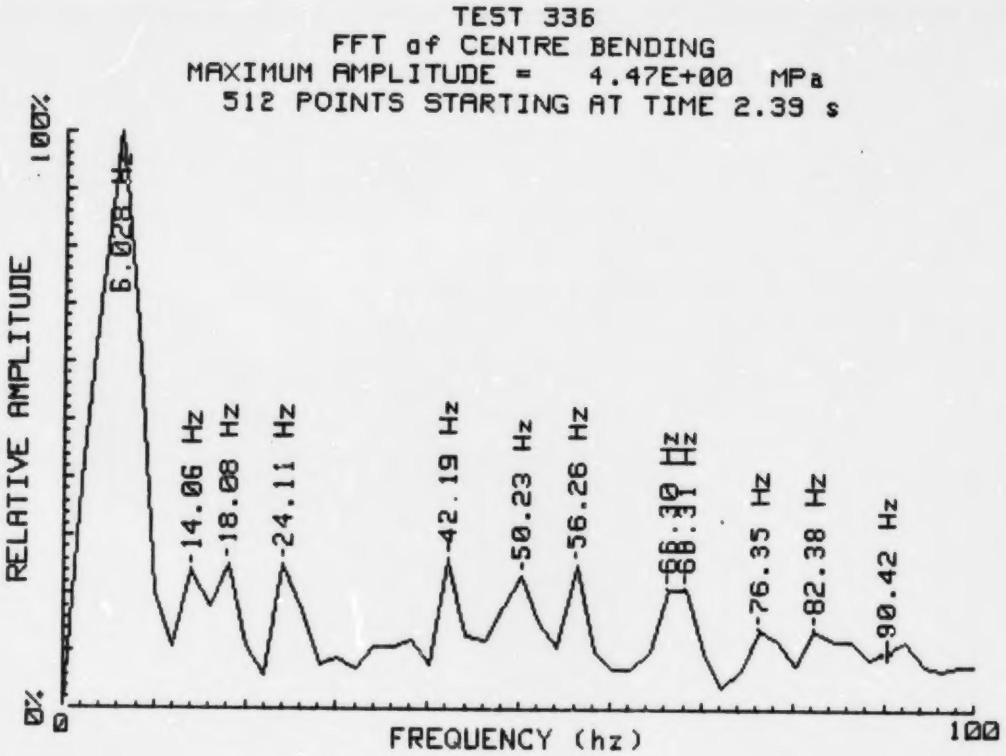
MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **TIME HISTORY OF THE MAXIMUM CENTRE BENDING SIGNAL (EVENT #336)**

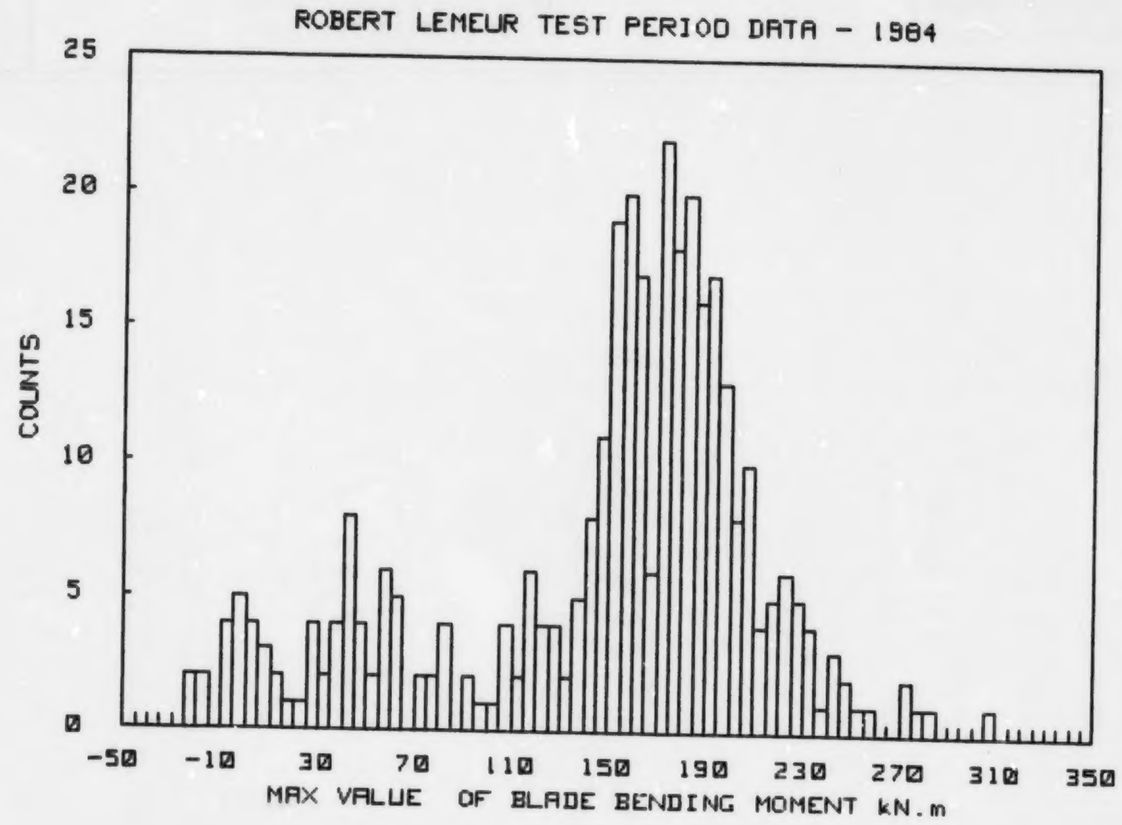
FIGURE No. 4.6.5-4



CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE:	FFT OF THE EVENT #336, CENTRE BENDING SIGNAL
		FIGURE No. 4.6.5-5	



CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: FFT OF THE EVENT #336 CENTRE BENDING SIGNAL, FREE VIBRATIONS FIGURE No. 4.6.5-6


ROBERT LEMEUR TEST PERIOD DATA - 1984

TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 340
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:148.24
AND ITS STANDARD DEVIATION IS:66.172

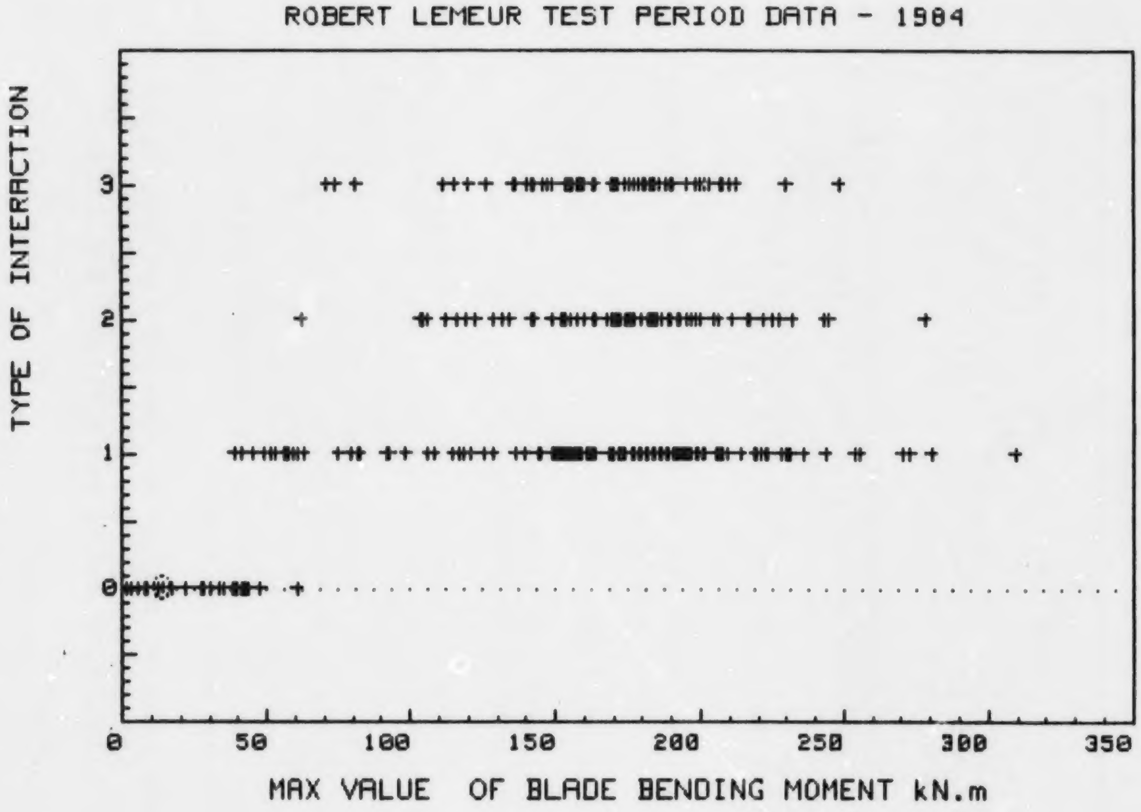
ALL DATA USED

**CANADIAN
MARINE
DRILLING
LIMITED**

**MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS**

**TITLE:
"MAXIMUM VALUE OF BLADE BENDING MOMENTS"**

FIGURE No. 4.6.6-1



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 321

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE OF LOC. and DIR. OF MAX FORCE = 1 m

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: MAXIMUM BLADE BENDING MOMENTS FOR EACH TYPE OF EVENT** **FIGURE No. 4.6.6-2**

type of interaction to another, the maximums of maximum blade bending moments decrease with an increase of the interaction number. Highest blade bending moments were produced during the single impact events.

The dependance of the maximum value of blade bending moment on the mean value of shaft torque is shown on Figure 4.6.6-3. The maximum value of BBM occurred at the maximum continuous torque of 151 kN*m. There is a strong correlation between the shaft torque and the maximum BBM.

Figure 4.6.6-4 shows two correlations between the mean value of shaft thrust and the maximum values of BBM. It can be concluded that the highest value of BBM occurred at approximately 310 kN average thrust and, in general, higher ahead thrust lead to higher maximum BBM values.

Figure 4.6.6-5 shows the correlation between the maximum values of the BBM and durations of blade impact. An important conclusion can be deduced from it: Highest values of BBM have very short durations (less than 70°). The second highest maximum BBM had a duration of 20° only (0.016 sec).

Figure 4.6.6-6 shows the correlation of the maximums of BBM and maximum blade forces.

The best-fit line is:

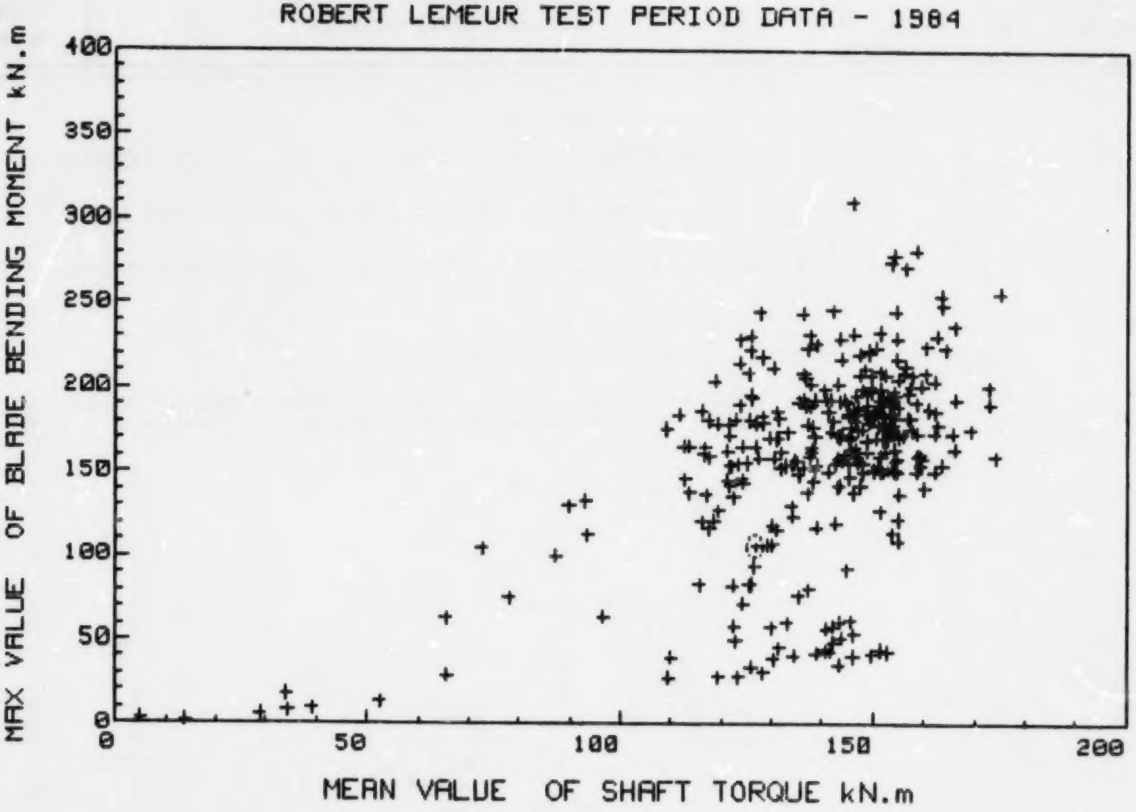
Max value of BBM = 0.77 * (maximum value of blade force) + 11 where BBM is in kN*m and blade force in kN.

The ratio of BBM to blade force gives the arm, at which the force is applied, measured from the blade's root. The average location of the forces is 0.77 m above the root ($r/R = 0.9$). It can be noted, however, that for the high values of blade bending moments, the ratio is lower (0.55 m), while for the lower values of maximum BBM's, the ratio is higher (1.2 m). This confirms the conclusions regarding the location of maximum blade forces, developed in Section 4.4.

The maximum bending moment at the root of the blade can be converted into the stresses at that location. The stresses can be calculated using the following formula:

$$\sigma = (BBM/I) * Y$$

Where Y is the distance, in meters, from the neutral axis to the outermost fiber of the blade section.



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 318

DATA SATISFIED THE FOLLOWING TEST(S)

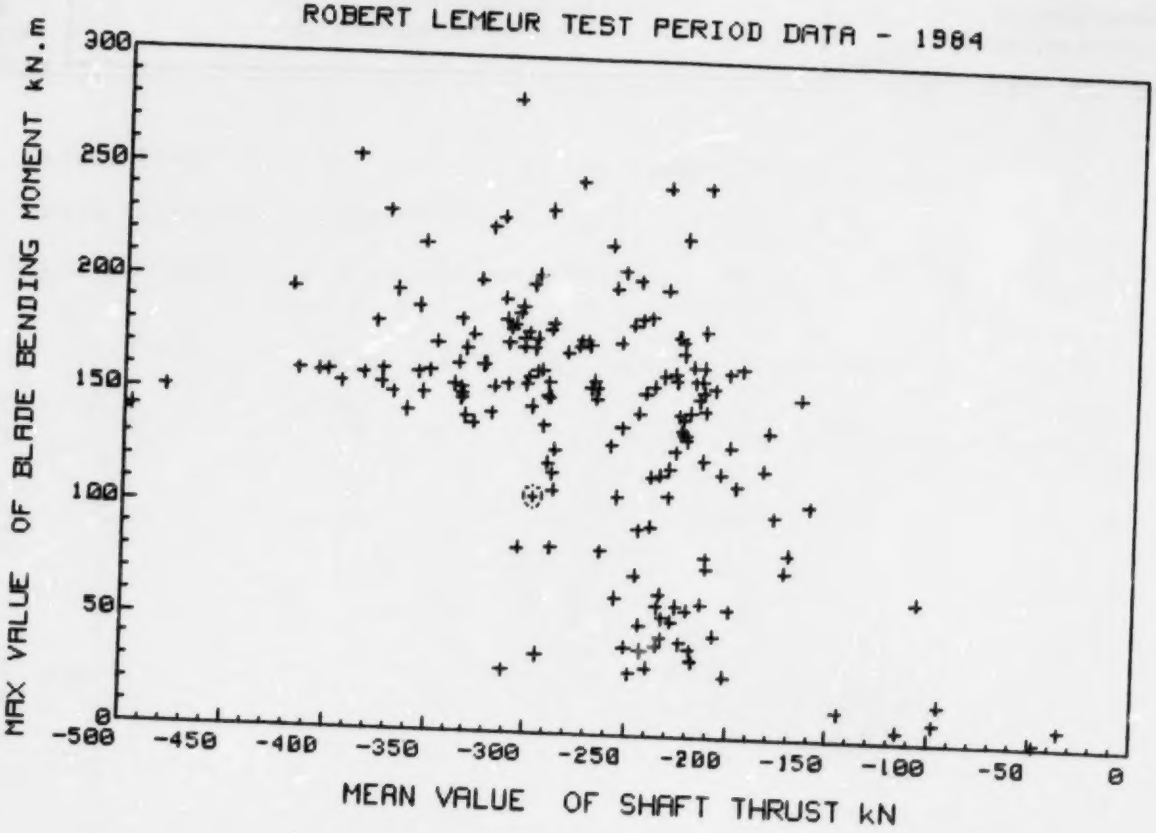
FORCE SENSE OF LOC. and DIR. OF MAX FORCE = 1 m

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: MAXIMUM BLADE BENDING MOMENT VERSUS MEAN SHAFT TORQUE

FIGURE No. 4.6.6-3

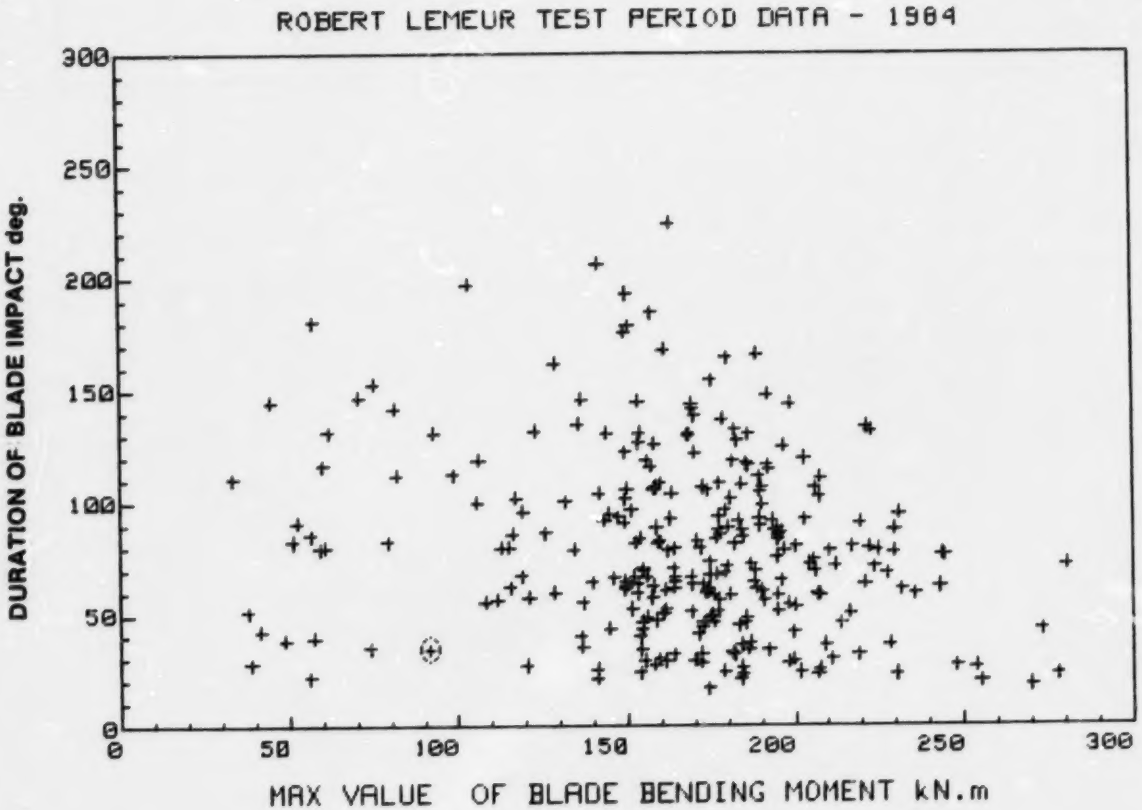


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 179

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE OF LOC. and DIR. OF MAX FORCE = 1 m

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: MAXIMUM BLADE BENDING MOMENT VERSUS MEAN SHAFT THRUST** **FIGURE No. 4.6.6-4**

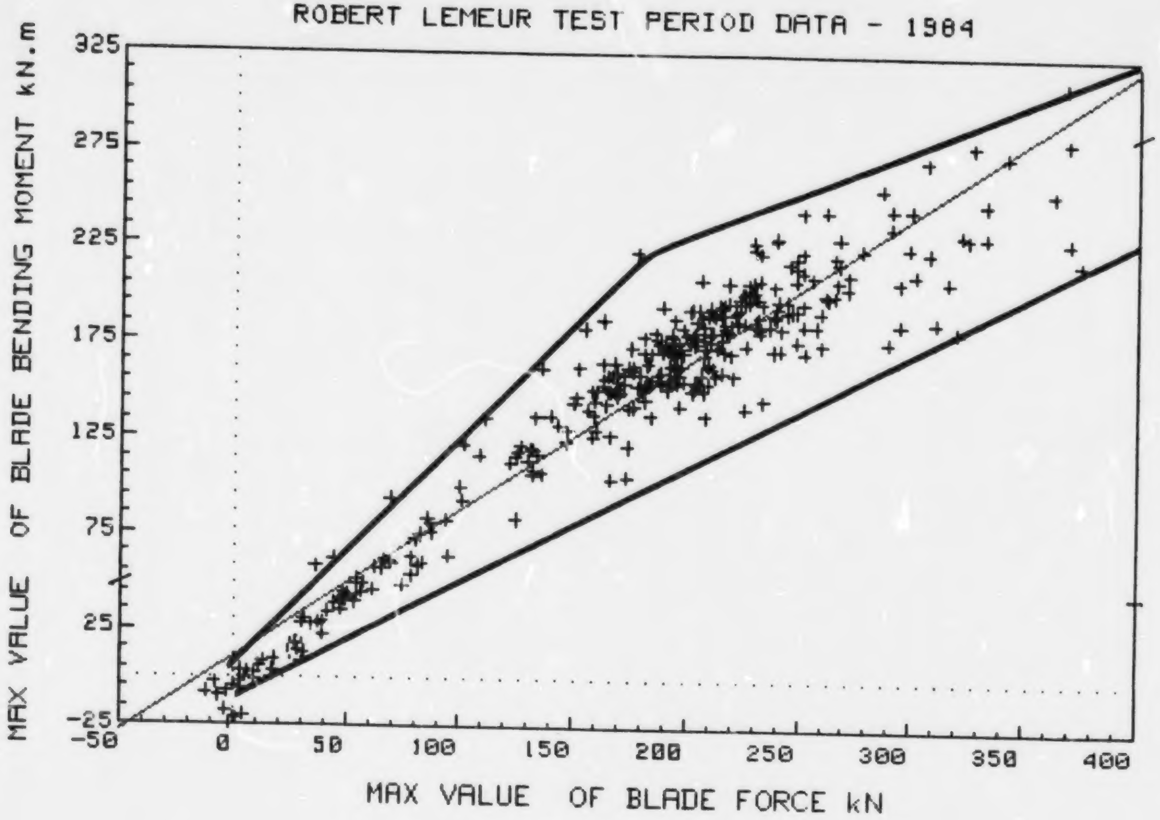


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 274

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE OF LOC. and DIR. OF MAX FORCE = 1 m

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: DURATION OF BLADE IMPACT VERSUS MAXIMUM BLADE BENDING MOMENT FIGURE No. 4.6.6-5



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 340

ALL DATA USED

Y = .771346373205 *X + 10.9621828131

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: MAXIMUM BLADE BENDING MOMENT VERSUS MAXIMUM BLADE FORCE

FIGURE No. 4.6.6-6

Taking I_R as $114.9 * 10^{-6}$ m^4, and Y as 0.6 * (section thickness at that radius), the following numbers are calculated:

$$\sigma = (310 * 10^3/114.9 * 10^{-6}) * 0.6 \times 0.152 = 246 \text{ MPa}$$

Thus, at the root, 95% of the yield of Cunial has been achieved.

Along the blade, however, the stress distribution due to 310 kN*m was as follows:

r/R	Bending Moment kN*m	Section Inertia $m^4 * 10^{-6}$	Y m	Maximum Stress MPa
0.93	0	-	-	-
0.8	72.1	9.37	0.037	285
0.7	127.6	19.25	0.041	272
0.6	183.1	33.62	0.052	283
0.5	238.6	55.31	0.065	280
0.4	294.1	94.47	0.083	258
Root	310.0	114.9	0.091	246

The above table shows that the yield of the blade material occurred in the blade at r/R > 0.5. The yielding however was on the compression side of the blade section.

4.6.7 Conclusions

- Event Duration:

i. High impact forces are of short duration.
ii. Average blade force event duration is approximately equal to the blade width (in degrees).
iii. The longer impact durations are associated with lower blade forces.
iv. There is no correlation between the duration of torque events and the magnitude of blade impact forces.
v. For prolonged torque events (duration > 1 sec) the level of blade forces are high.

- Blade Position at Instant of First Contact With Ice:

i. The presence of a skeg in front of the nozzle has pronounced influence on the position of ice contacting propeller blades.
ii. There is a "shadow" at 160° and 320° of blade orientation angle where no interaction takes place.
iii. Maximum interaction occurres at approximately 50° and 240° of blade position at the time of first contact.
iv. Increase of ship's speed magnifies the shadow effect.
v. For the propulsion shaft strength calculations, the blade force should be applied at 80° and 270°
vi. On the assumption of the equal stiffness of the shaft in the vertical and horizontal direction, the horizontal displacements of shaft under ice impact loads should be more pronounced than the vertical ones.

- Displacement of Blade Under Load:

i. Displacement of the blade tip under the maximum blade force is estimated to be of the order of 1 cm.
ii. When the blade is being bent forward by ice, it looses most of its hydrodynamic load.
iii. When the blade is released (after ice load is gone) its motion magnifies the hydrodynamic load significantly.
iv. "An average" hydrodynamic load on the blade during loading and unloading by ice is expected to grow significantly (increase of thrust and torque).

- Blade Free Vibrations:

i. For the impact force having its period equal to the period of freely vibrating blade, the dynamic magnification factor is approximately 1.7.
ii. Damping factor for freely vibrating blade is less than 0.09.
iii. There is a time delay of 0.005 sec between the excitation and response, due to inertial effects.
iv. The heavy damping is present for both large and small amplitude vibrations of the blade in water.

v. The blade added mass if 4 times the mass of the blade.

- Dynamic Magnification of Blade Response:

  i. As the maximum values of blade forces are associated with short impulse durations (see Figure 4.6.1-2) they are subject to dynamic magnification.
  ii. For durations longer than 0.05 sec (63°) the dynamic magnification is larger than 1, that is the forces estimated using the static calibration method are actually less than predicted. Maximum dynamic magnification in water is assessed to be 1.3.
  iii. For the durations shorter than 0.05 sec. which corresponds to blade width, the dynamic magnification is less than 1. That is the forces are actually higher than those estimated from the static calibration tests. The dynamic magnification factors are of the order of 0.7.
  iv. For MV Robert LeMeur the issue of dynamic magnification is not relevant, since the actual stresses were measured. However, when extrapolating to other propellers, care should be taken in the assessment of the actual ice impact forces, including dynamic effects.
  v. More detailed analysis is needed in order to reliably assess the magnitudes of impact forces especially those having short durations.

- Blade Bending Moment

  i. The maximum value of BBM recorded during the tests was 310 kN*m, which is 4.8 times higher than the maximum BBM recorded during open water transit and approximately 6 times larger than the calculated BBM in bollard condition.
  ii. Highest BBM occurred during the single impact events.
  iii. The higher the average shaft torque and shaft thrusts, the higher the BBM.
  iv. The highest BBM's occurred during very short impacts (0.016 sec.).
  v. Yielding, in compression, occurred in the blade during the maximum blade bending moment event.
  vi. More analytical work is required to assess the stress levels in the blade under the various blade loading conditions.

4.7 Comparison With The Ice Interaction Model

4.7.1 General

Analytical models are, by definition, mathematically precise descriptions of the phenomena, containing many interrelated variables. The number of simplifying assumptions underlying such models is large. In order to validate such models, many strictly controlled experiments are needed, where one variable is being tested at a time.

Having analysed 343 tests, it is concluded that the tests provided much useful information in a "lumped parameter" way, that is only the large changes of the most important parameters (RPM, pitch angle, power setting) resulted in the changed values of the investigated quantities (blade force, shaft thrust, shaft torque).

Consequently, it was decided to restrict the ice-blade interaction model to those parameters which can be:

- Verified by full scale testing.
- Easily applicable for regulatory and design purposes.

The analysis presented in the Milestone 1 will serve as a supporting and explanatory material to the relationships derived from the full scale data. It will also serve the purpose of extrapolating of MV Robert LeMeur data to other ships in the future research.

The proposed model is presented in Sections 4.7.2 to 4.7.6.

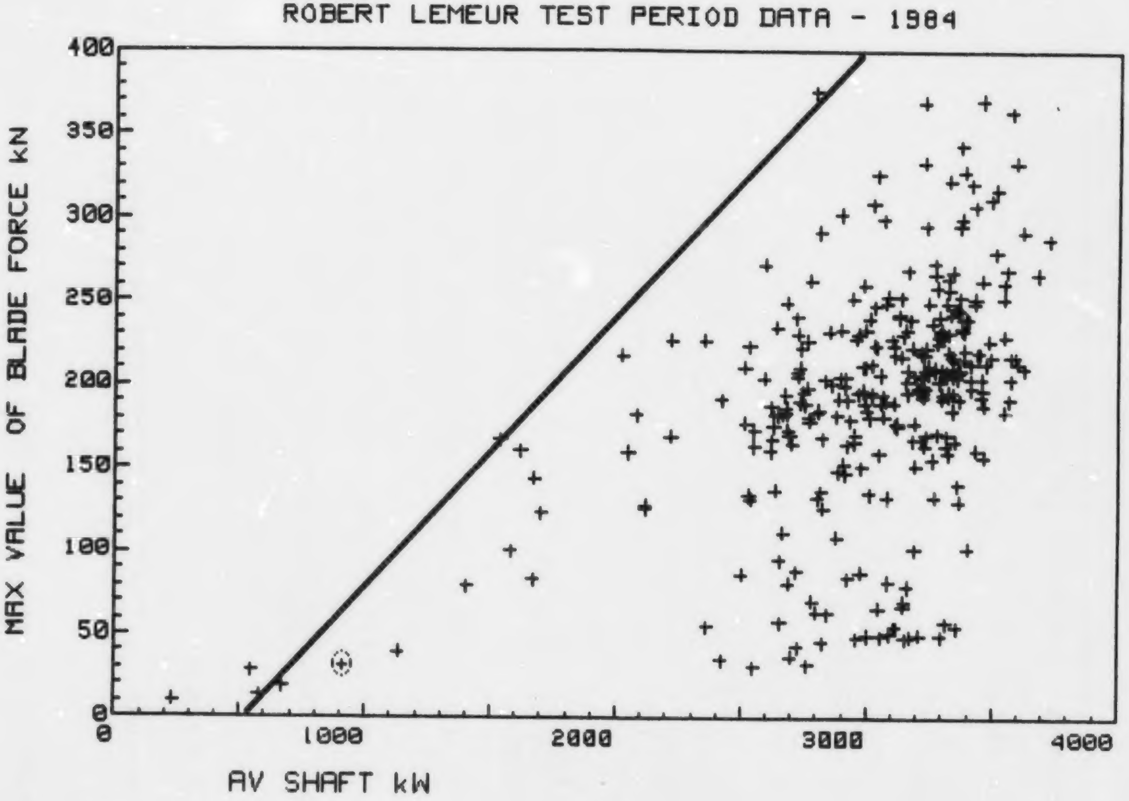
4.7.2 Blade Force

- Magnitude of blade force: $(BF)_{max} = -80 + 0.16 * \text{shaft power}$ (power in kW, force in kN). Figure 4.7-1 shows this relationship.

- Direction: Perpendicular to the blade chord at 0.47 r/R.

- Radial point of application: $r/R = 0.7$

- Circumferential point of application: 1/2 way between the leading edge and the centre of the blade. (This value requires further verification).



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 309

DATA SATISFIED THE FOLLOWING TEST(S)

FORCE SENSE OF LOC. and DIR. OF MAX FORCE = 1

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE:	MAXIMUM BLADE FORCE IN FUNCTION OF SHAFT POWER
		FIGURE No. 4.7-1	

- Duration: Time needed to rotate the blade through the distance equal to the blade chord at the point of load application, at rated RPM.

Note that the above given expression contains in it the hydrodynamic load on the blade.

4.7.3 Blade Bending Moment

For calculating the stresses in the blade at r/R = 0.37, the following expression should be used:

$$(BM)_{max} = \text{Shaft kW}/11$$

Figure 4.7-2 illustrates this relationship.

Duration of this blade bending moment should be equal to the duration of the maximum blade force.

4.7.4 Blade Torque Generating Force

The maximum torque-generating force, acting in propeller disk plane is five times the maximum hydrodynamic bollard condition steady state torque generating force. (Torque - force is defined as torque/lever arm.)

$$Q_{Max}/1 \text{ blade} = [(\text{Shaft kW}) / 4 * (2\pi * \text{RPM})] * 60 * 5 = (12 \text{ Shaft kW}) / \text{RPM}$$

Torque in kN*m, shaft kW and RPM refer to the bollard condition.

Duration of this torque force should be 0.55 seconds.

Point of the application of the torque force is:

r/R = 0.7

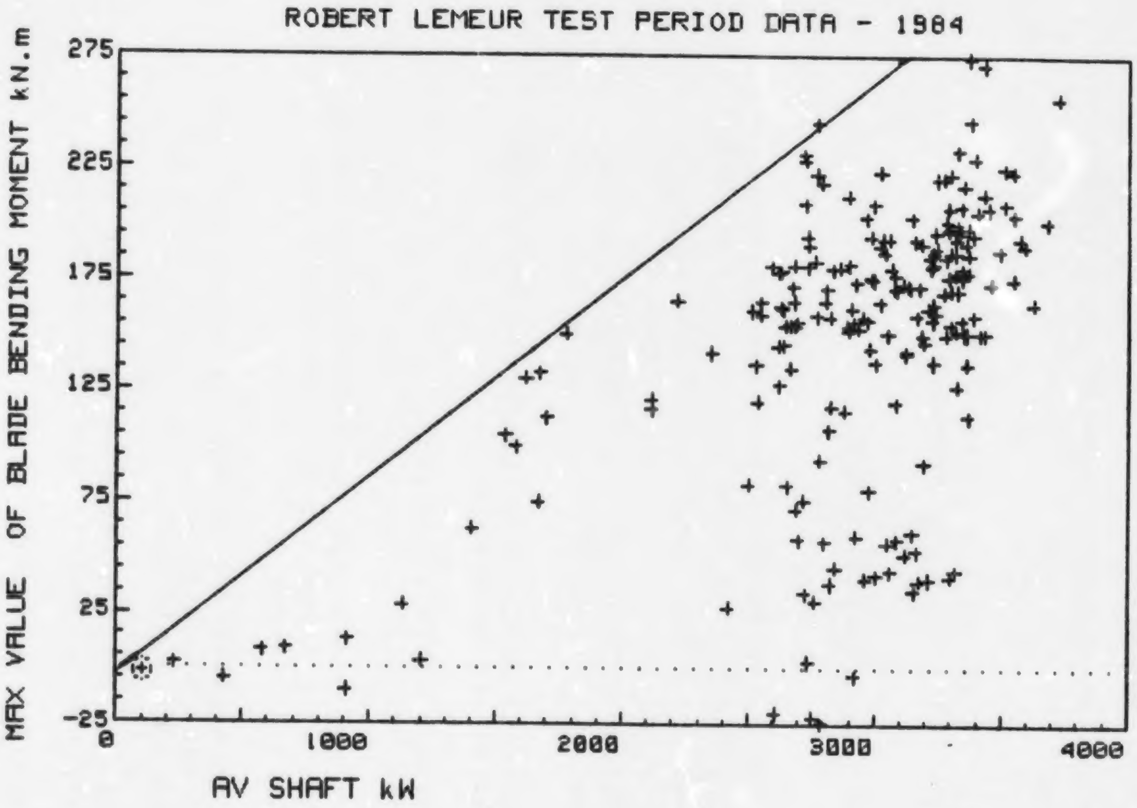
4.7.5 Shaft Torque

The maximum shaft torque is twice the maximum bollard shaft torque. Its duration is 0.55 sec. (See Figure 4.6.1-3)

Points of application of the force couple is: r/R = 0.7

4.7.6 Shaft Thrust

The maximum thrust acting on the propeller shaft is: 4.6 times the bollard thrust. This number requires further verification. Its duration is 0.05 seconds



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 207

DATA SATISFIED THE FOLLOWING TEST(S)

MEAN VALUE OF RUDDER ANGLE > -10 deg
AND
MEAN VALUE OF RUDDER ANGLE < 10 deg

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: DEPENDANCE OF THE MAXIMUM BLADE BENDING MOMENT ON THE AVERAGE SHAFT POWER FIGURE No. 4.7-2

4.8 Blade Model Assessment

4.8.1 Introduction

A simple blade model was constructed (see Milestone 1) in order to answer the question:

Given the force magnitude, direction and point of application what are the stresses at any point of the blade?

For a simple cantilever beam, the stress due to bending at any radial location can be calculated as follows:

$\sigma_{bend} = F * R * ([r_o/R]-[r_x/R])/1000\ SM = F * \Delta r/1000\ SM$ (Ref. 4.6.4-1)

Where F is the force in kN, R is blade radius in meters, r_o/R and r_x/R are nondimensional radial locations of the force and of the point under investigation respectively, SM (r_x/R) is the section modulus of the blade section passing through the point under investigation, and σ_{bend} is in MPa.

Two sources of information suitable for verifying the above formulation are available:

- Stress gauges vibration tests.
- Full scale tests.

Both sources have been used for verification. Using the calibration tests, a direct comparison between the measured and calculated values is possible.

Full scale data tests can be used by comparing stress gauge response (measured value), to the input force and calculated point of application. Knowing the force and point of its application, a simple beam model can be used to compare the calculated stresses with those measured. This way the "A" Matrix verification is made.

4.8.2 Calibration Test Data

- Calibration Point: #2 Test #1
- Location of Force: r/R = 0.98 Radial
- c/w = 0.15 Chord-Wise
- Magnitude: 26.3 kN

- Direction: Horizontal and inclined 4^o to the blade section pitch line ($\cos 4^o = 0.9976$).

- Calibration Factors:

i. Bending Gauges: 45.2 MPa/V
ii. Torque Gauges: 123.0 MPa/V
iii. Gauge Output:

GAUGE NO.		OUTPUT	GAUGE STRESS
C.B.	1	+0.542	+ 24.5 MPa
T.E.Q.	2	-0.234	- 28.8 MPa
L.E.B.	3	+0.623	+ 28.2 MPa
C.Q.	4	-0.463	- 56.9 MPa
T.E.B.	5	+0.239	+ 10.8 MPa
L.E.Q.	6	-0.451	- 55.5 MPa

The width of the blade at $r/R = 0.98$ is, approximately 1.3m, so the distance from the leading edge is $0.15 * 1.3 = 0.195$m. At that point, the distance to the first gauge is 0.55m.

Blade segment at $r/R = 0.6$ can be approximated by a circular segment having the following characteristics: Chord length 1.046 m (see blade properties), and; section thickness 0.0868 m.

The radius of the circle approximating blade contour on the suction side and the angle φ within which the section is contained (see Figure 4.8.2-1) are calculated by solving the following equations:

$$\bar{R}\,(1 - \cos\varphi) = 0.0868$$

$$\sin\varphi = 1.046\,/(2\bar{R})$$

The solution of which is:

$$\varphi = 18.8^o$$

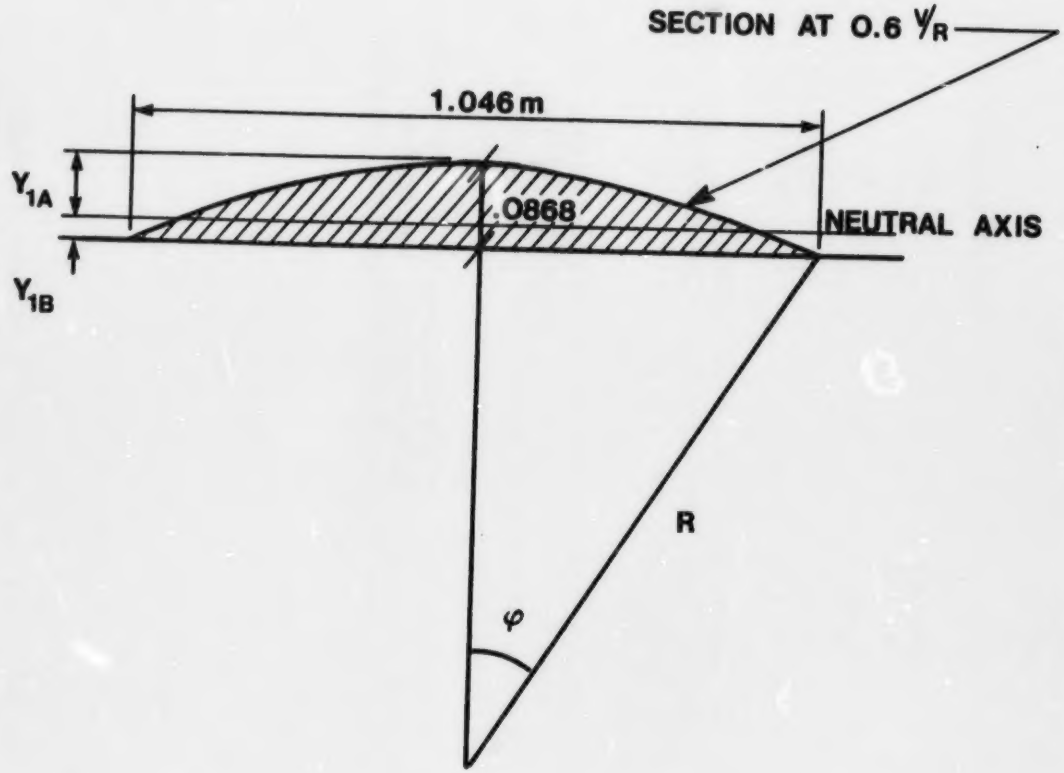
$$\bar{R} = 1.619 \text{ m}$$

Having established the geometry of the segment, the position of neutral axis can be found from the equation:

$Y_{ia} = \bar{R}\,[1 - 2\sin^3\varphi/(3 * (\varphi - \sin\varphi\cos\varphi))]$ from reference no. 4.6.4-1. Substituting for $\bar{R}$ and φ, we will obtain:

$$Y_{1A} = 0.0518$$

$$Y_{1B} = 0.0868 - 0.0518 = 0.035$$


SECTION AT O.6 $^{r}/_{R}$
1.046 m
Y_{1A}
.0868
NEUTRAL AXIS
Y_{1B}
R
φ

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MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: BLADE SECTION GEOMETRY

FIGURE No. 4.8.2-1

Thus the ratio of Y_{ia}/Y_{ib} = 1.48 signifies the ratio of stresses at compression side to that at tension side and $Y_{ia}/t = 0.6$, $Y_{ib}/t = 0.4$. Naval Architecture Handbook (Ref 4.8.2-1) gives this ratio as 1.37 for fixed pitch propellers.

Centre bending stress can now be calculated using the simple cantilever beam theory, as follows:

$$\sigma_{tens} + \sigma_{compr} = F * \Delta r * (Y_{ia} + Y_{ib})/(1000 * I) = 37.3 \text{ MPa}$$

This stress differential would exist on the surface of the blade. However, since the gauges are recessed, the correction for their location must be applied. This can be done on the assumption that the stress distribution across the section is linear:

$$\sigma_{surface}/\sigma_{recess} = t_{Max}/t_{rec} = 0.0868/0.0638 = 1.36$$

Thus the stresses at gauges locations must be reduced by this factor. The stress at the gauge is:

$$\Delta\sigma_{gauge} = 37.3/1.36 = 27.4 \text{ MPa}$$

The actually measured stress was 24.5 MPa, and therefore it is concluded that the simple cantilever beam theory over estimates the stress differential by 12%. If this difference was split equally between compression and tension side, then the error would have been 6%. Since the error is on the safe side (over estimation of stresses) it can be concluded that the simple beam method is sufficient, to predict the bending stresses at 0.6 r/R. Similar reasoning can be applied to the strain gauges located at r/R = 0.47.

The vertical distance between the point of application of the force to the strain gauges is approximately 0.705 m. The section's inertia at that point is $65.1 * 10^{-6}$ m^4. Due to the skewness of the gauge locations it is difficult to estimate the thickness of the profile at the gauge mounting section, and consequently, we will use the average values between and gauges.

The maximum thickness of the profile at flat radius is 0.1167 m. Since the gauges are located 0.250 m/cos 35^{o} = 0.3 m apart (Ref 4.8.2-2). The mean thickness of the material at the gauges is estimated to be:

$t_{Max} = 0.9(t)_{Max}$ profile

Stress difference is then:

$\sigma_{tens} - \sigma_{compr} = F * \Delta r * 0.9 * t_{Max}/(1000 * 65 * 10^{-6})$

Substituting for $t_{Max} = 0.1167$, and $\Delta r = 0.705$ we will obtain:

$\sigma_{tens} - \sigma_{compr} = 30$ MPa

Introducing the gauge recess correction of 0.73 (REF No. 4.6.5-1), we will obtain

$\sigma_{tens} - \sigma_{compr} = 21.9$ MPa

The mean stress between the two gauges is

$(\sigma_{L.E.B.} + \sigma_{T.E.B.}) * 1/2 = 19.5$ MPa

Thus the calculated stress differential is again 12% higher then the measured values; error being on the safe side.

4.8.3 Test Data

Event No. 72 (highest blade force) will be used for the purpose of comparing the calculated values of bending stresses.

Calculated radial location at the time of the F_{Max} is 0.59 m above the root of the blade, which translates into $r/R = 0.76$. Circumferential location for the force is 0.

Using simple beam model, the following calculation can be made:

$\sigma_1 - \sigma_2 = (375*(0.76-0.6)*1.5/(1000*33.62*10^{-6})*0.73*0.0868$

$\sigma_1 - \sigma_2 = 170$ MPa

Thus the ratio of measured to calculated stress difference at the time of F_{Max} is:

$\frac{170}{205} = 0.83$

Thus a 17% discrepancy exists between the values calculated by [A] matrix and those calculated by using the simple beam method.

4.8.4 Conclusions

- The simple beam method predicts well (within 12%) the bending stresses along the centerline of the blade.
- The model overpredicts the stresses.
- When compared to the dynamic force calculated using the [A] matrix, the error of the method used here as 17% (under prediction).
- The compressive and tensile stresses are not equal. Their ratio is 1.48:1
- For the case investigated, the blade would yield in compression first at relative radius of 0.6.

4.9 Shaft Torque And Thrust Models

4.9.1 Introduction

The development of a model which estimates ice induced blade loads from the propeller shaft response has several advantages. The magnitude and direction of the load on the propeller can be estimated, and then compared with the blade data. The type of ice/propeller interaction (blockage, milling, single impact) can be deduced. The response of the propulsion control system can be included in the model. This section of the report describes the methodology, and the corresponding results from various events studied.

4.9.2 Methodology

A three degree of freedom lumped mass longitudinal and torsional model was developed and programmed for the Hewlett Packard 9845B desk top computer. Three degrees of freedom were chosen because it was the simplest configuration that included all the major components (propeller, gear wheel, flexible coupling). Using these models, torque and thrust waveforms developed from measured results were applied to the propeller. The resulting waveforms on the shaft, where the torque and thrust strain gauges were located, were then calculated and plotted.

The damping for the first model response was initially estimated by calculating the logarithmic decrement from measured data. However, the damping varies with the pitch of the propeller, temperature of flexible coupling, and variations in other components; also the logarithmic decrement assumes a single degree of freedom system. Therefore, the damping ratio for the propeller blade and the shafting were varied until the damping measured on the shaft torque and thrust gauges matched the output of the model.

The longitudinal natural frequencies were approximately five times higher than the torsional natural frequencies. Therefore, mode coupling between the longitudinal and torsional shafting vibration was neglected.

The torsional model used is shown in Figure 4.9.2-1. The solution to the response of the model to an arbitrary torque input on the propeller was derived by using the mode superposition technique [Reference 4.9.2-1]. The equation of motion of the propulsion model was:

$$[J][\ddot{\theta}] + [g_T][\dot{\theta}] + [C_T][\dot{\theta}] + [k_T][\theta] = [F_T]$$

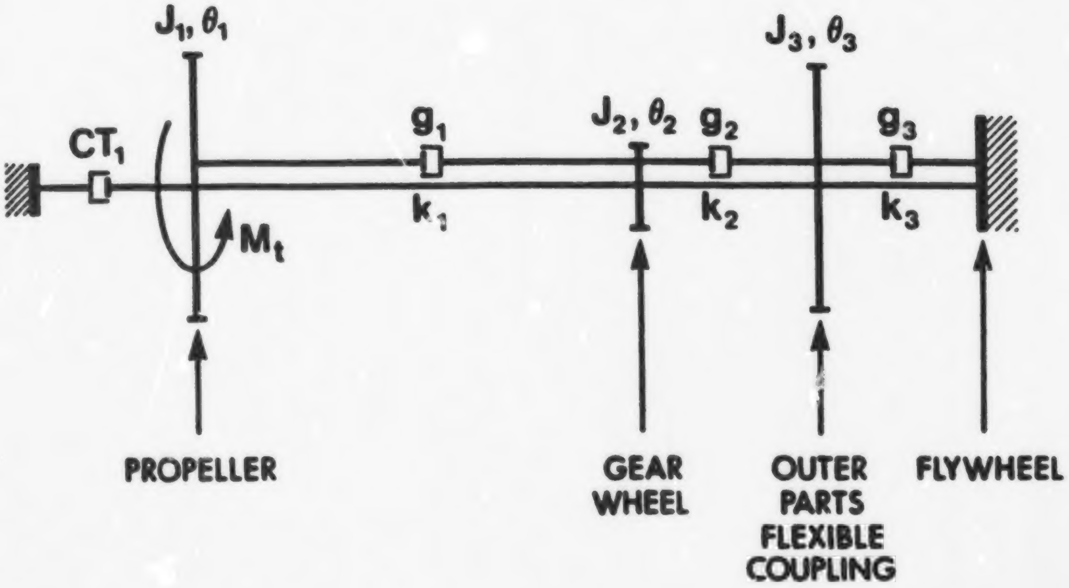
Where: $[J]$ = Mass moment of inertia matrix
$[g_T]$ = Shaft damping matrix (proportional to $[K_T]$)
$[C_T]$ = Propeller damping matrix (only one nonzero element)
$[k_T]$ = Torsional stiffness matrix
$[F_T]$ = Force matrix (torque on propeller blade)
$[\theta]$ = Twist of shaft at each node

The twist of the shaft at each node was solved for each point in time. The torque on the shaft where the gauges were located was then calculated by the following equation:

$$T = k_1(\theta_2 - \theta_1) \quad \text{(Ref No. 4.9.2-2)}$$

Where: T = Torque on shaft
k_1 = Torsional stiffness of shaft
θ_1 = Twist at propeller blade
θ_2 = Twist at gear wheel

The free vibration solution to this model was obtained. The two lowest natural frequencies computed by M.A.K.'s (the engine manufacturer) torsional vibration analysis [Ref. 4.9.2-3], agreed with those computed from


J_1, θ_1
CT_1
M_t
g_1
k_1
J_2, θ_2
g_2
k_2
J_3, θ_3
g_3
k_3
PROPELLER
GEAR WHEEL
OUTER PARTS FLEXIBLE COUPLING
FLYWHEEL

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PARAMETERS

TITLE: M.V. ROBERT LEMEUR
TORSIONAL MODEL

FIGURE No. 4.9.2 - 1

the three degree of freedom model. The values of these frequencies was approximately the same as those estimated from full scale data. The detailed development of the model is provided in Appendix D.

	Full Scale Data	Model	M.A.K.'s Model
First Natural Frequency	4.17 Hz	3.58 Hz	3.85 Hz
Second Natural Frequency	16.7 Hz	13.89 Hz	13.83 Hz
Third Natural Frequency	-	42.27 Hz	27.12 Hz
Fourth Natural Frequency	-	-	44.12 Hz

The solution of the equation of motion of the torsional response of the model to any form of torque input to the propeller blade, was computed and plotted by a program developed for the H.P. 9845B desk top computer. The centre bending signal is the best indication of the duration and shape of the load on the blade. Therefore, the shape and the duration of the centre blade bending signal was used as the shape of the torque input for the model (see Figure 4.9.2-2).

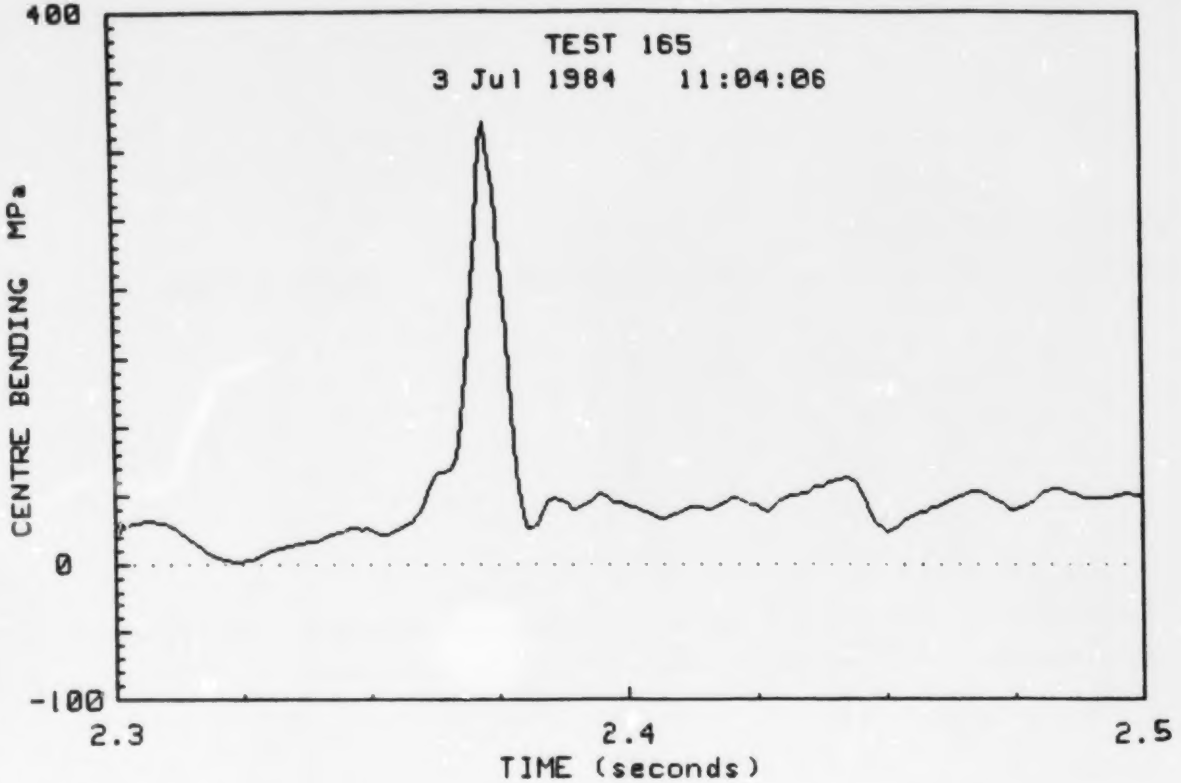
The longitudinal model is shown in Figure 4.9.2-3. The solution to the response of the model to thrust inputs on the propeller was derived by using the mode superposition technique. The equation of longitudinal motion of the propulsion model is:

$$[M][\ddot{X}] + [g_L][\dot{X}] + [C_L][\dot{X}] + [k_T][X] = [F_L]$$

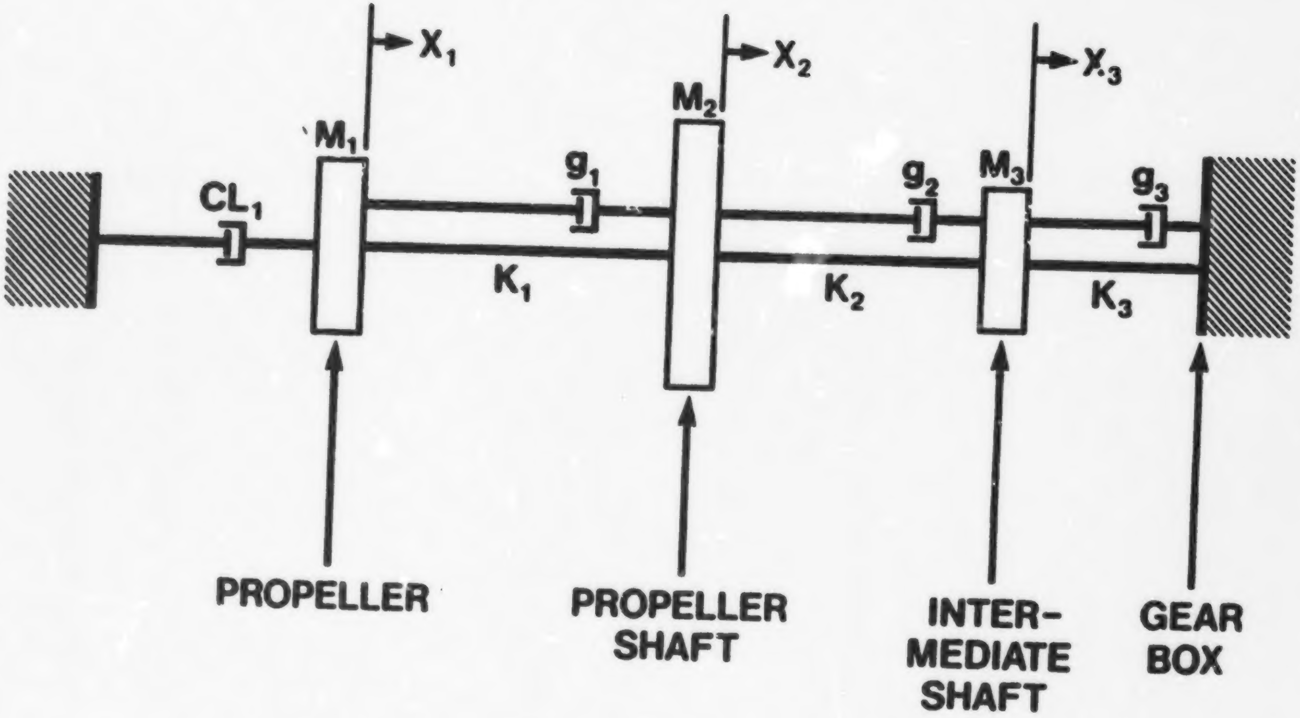
Where: $[M]$ = Mass matrix
$[g_L]$ = Shaft damping matrix (proportional to $[K_L]$)
$[C_L]$ = Propeller damping matrix (only one nonzero element)
$[K_L]$ = Longitudinal stiffness matrix
$[F_L]$ = Force matrix (thrust on propeller)
$[X]$ = Movement of shaft at each node

The longitudinal movement of the shaft at each node was solved for each point in time. The thrust on the shaft where the gauges are located was then calculated by the following:

$$F = -(K_3)(X_3)$$



CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: CENTRE BENDING SIGNAL FOR SINGLE IMPACT (TEST 165)** **FIGURE No. 4.9.2-2**


X₁
X₂
X₃
M₁
M₂
M₃
CL₁
g₁
g₂
g₃
K₁
K₂
K₃
PROPELLER
PROPELLER SHAFT
INTER-MEDIATE SHAFT
GEAR BOX

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MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE:
MV ROBERT LEMEUR
SHAFT LONGITUDINAL MODEL

FIGURE No. 4.9.2-3

Where: F = Thrust on shaft
K_3 = Longitudinal stiffness of shaft
X_3 = Movement of shaft aft of gauges

The free vibration solution of this model was obtained. The natural frequencies computed and estimated from full scale data are as follows:

	Model	Full Scale Data
First Natural Frequency	25.5 Hz	25 Hz
Second Natural Frequency	76.1 Hz	--
Third Natural Frequency	106 Hz	--

The shape and the duration of the centre bending signal was used as the shape of the thrust input for the model (see Figure 4.9.2-2). The response of the model was computed and plotted by a program similar to the torsional response program. A positive propeller thrust results in a negative (compression) shaft thrust. The detailed development of the model is provided in Appendix D.

4.9.3 Results

Damping from logarithmic Decrement (δ)

$$\delta = \ln (X_1 / X_2) = 2\pi \zeta_1 / (1 - \zeta_1^2)^{1/2}$$

X_1 / X_2 = ratios of two successive amplitudes

Longitudinal Damping (ζ_1)

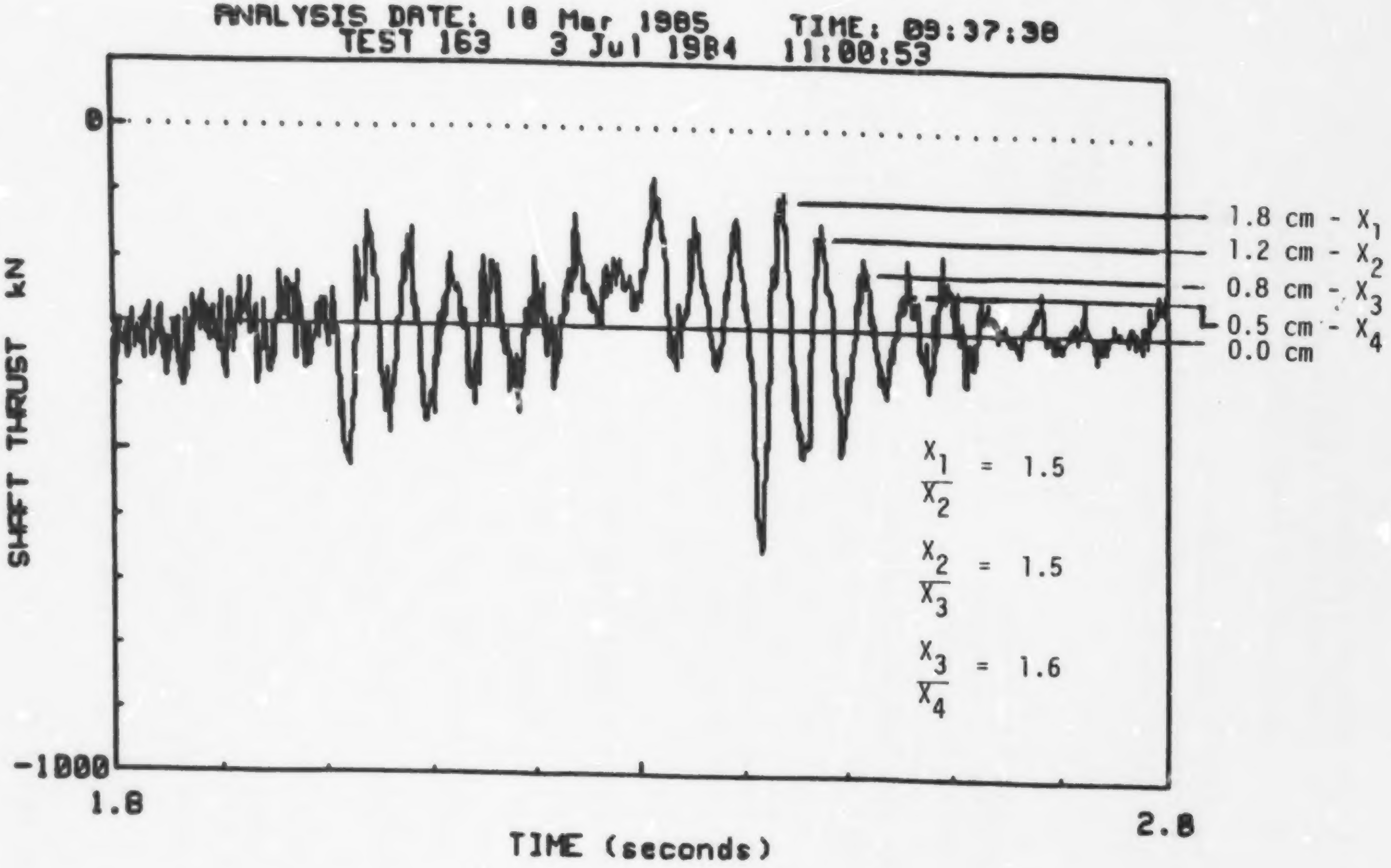
$$\delta = 2\pi \zeta_1 / (1 - \zeta_1)^{1/2}$$

From Figure: 4.9.3-1
$\delta = \ln (1.50) = 0.405$

$$0.405 = 2\pi \zeta_1 / (1 - \zeta_1)^{1/2}$$

If $(1 - \zeta_1^2)^{1/2} \approx 1$, then $\delta \approx 2\pi \zeta_1$.

$\zeta_1 = 0.405 / 2\pi$
$\zeta_1 = 0.064$



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MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: SHAFT THRUST SIGNAL, TEST 163

FIGURE No. 4.9.3 - 1

$\sqrt{(1 - \zeta_1^2)} = 0.998 \approx 1$

$\zeta_1 = 0.064$ - Longitudinal Damping for First Mode Response (6.4% of critical damping).

Torsional Damping (δ_2)

$\zeta = 2\pi \zeta_2 / \sqrt{(1 - \zeta_2^2)}$

From Figure: 4.9.3-2
$\zeta = \ln (2.45) = 0.896$

$0.896 = 2\pi \zeta_2 / \sqrt{(1 - \zeta_2^2)}$

If $\sqrt{(1 - \delta_2^2)} \approx 1$, then $\zeta = 2\pi \zeta_2$

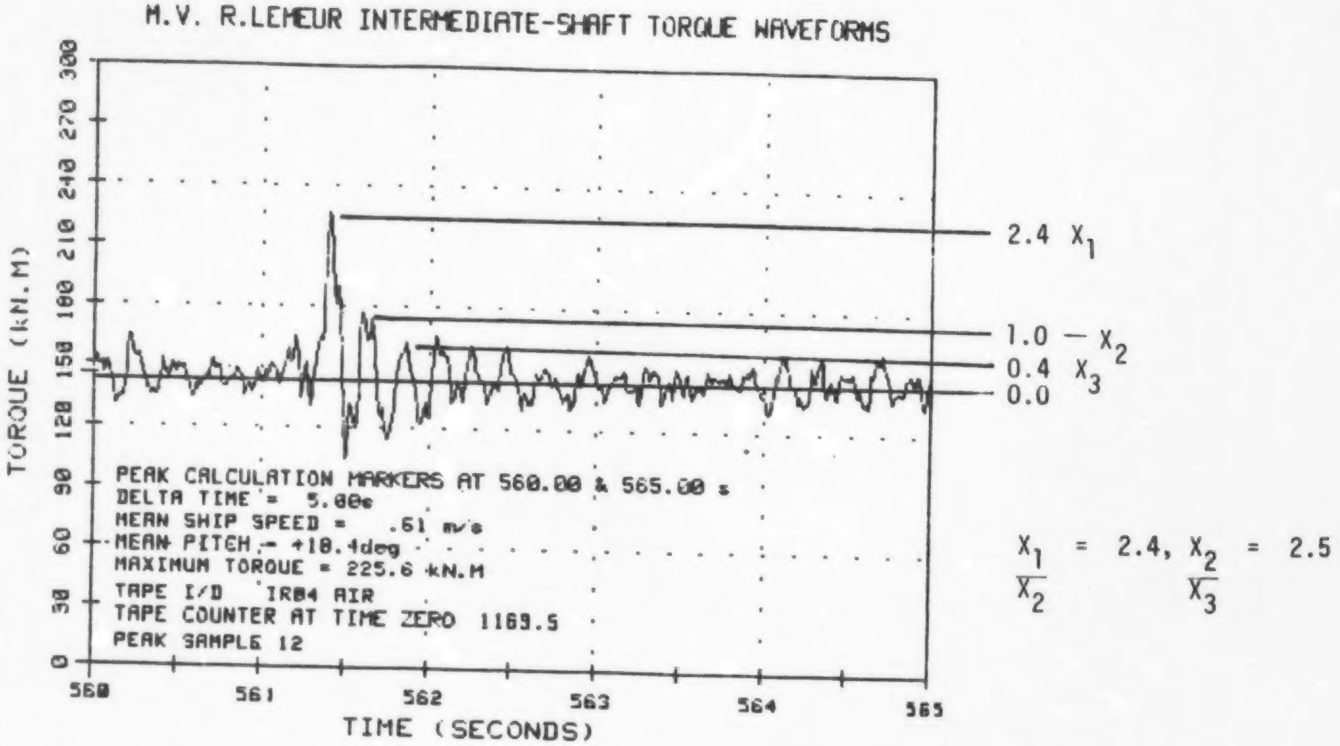
$\zeta_2 = 0.896 / 2\pi = 0.143$

$\sqrt{(1 - \zeta_2^2)} = 0.99 \approx 1$

$\zeta_2 = 0.143$ - Torsional Damping for First Mode Response (14.3% of critical damping)

Three different shapes of torque and thrust waveforms were input to the model: triangle, sine, and square. The duration time for each of these signals was varied, and the peak magnitude kept constant (100 kN for thrust and 100 kN*m for torque). The corresponding plots of torque and thrust at the propeller shaft, predicted by the models, were obtained. The results are listed in Table 4.9.3-1 and Table 4.9.3-2. The impulse is the area enclosed by the input waveform ($I = \int F dt$) and is proportional to the momentum input to the propeller.

Figure 4.9.3-3 illustrates the measured torque and thrust response of the shafting for test No. 165, which is a short duration impact (0.1 - 0.3 seconds). The estimated variation from the mean load on the propeller, and the predicted response to this load, is shown in Figure 4.9.3-4 and Figure 4.9.3-5. In this event it appears that three blades were hit with ice. The first impact resulted in a large axial load (500 kN) and a relatively small torque load (185 kN*m) on the propeller. The second impact gave a high torque load (400 kN*m) and a small axial load (150 kN*m). The third impact gave relatively small loads in both directions. The predicted peak variation from the mean shaft torque and thrust was 85 kN*m and 649 kN and the measured values were 97 kN*m and 600 kN respectively. This illustrates that the predicted and measured torque and thrust waveforms were very similar.



$$\frac{X_1}{X_2} = 2.4, \quad \frac{X_2}{X_3} = 2.5$$

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **SHAFT TORQUE DAMPED RESONANCE SIGNAL FROM 1982 TEST PERIOD**
		FIGURE No. 4.9.3-2

INPUT PROPELLER THRUST = 100 kN

SHAPE	DURATION (sec)	PEAK SHAFT THRUST FROM MODEL (kN)	IMPULSE (kN. sec)
Sine	0.02	155	1.28
	0.04	160	2.56
	0.06	140	3.82
	0.08	120	5.09
Triangle	0.02	135	1.00
	0.64	140	2.00
	0.06	120	3.00
	0.08	105	4.00
Square	0.02	170	2.0
	0.04	170	4.0
	0.06	170	6.0
	0.08	170	8.0

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TITLE: EFFECT OF SHAPE AND IMPACT DURATION ON THRUST RESPONSE OF SHAFT

TABLE 4.9.3-1

INPUT PROPELLER TORQUE = 100 kN.m

SHAPE	DURATION (sec)	PEAK SHAFT TORQUE FROM MODEL (kN.M)	IMPULSE (kN.M sec)
Sine	0.02	22	1.28
	0.04	42	2.56
	0.06	56	3.82
	0.08	68	5.09
Triangle	0.02	17	1.00
	0.04	33	2.00
	0.06	45	3.00
	0.08	55	4.00
Square	0.02	38	2.0
	0.04	62	4.0
	0.06	80	6.0
	0.08	105	8.0

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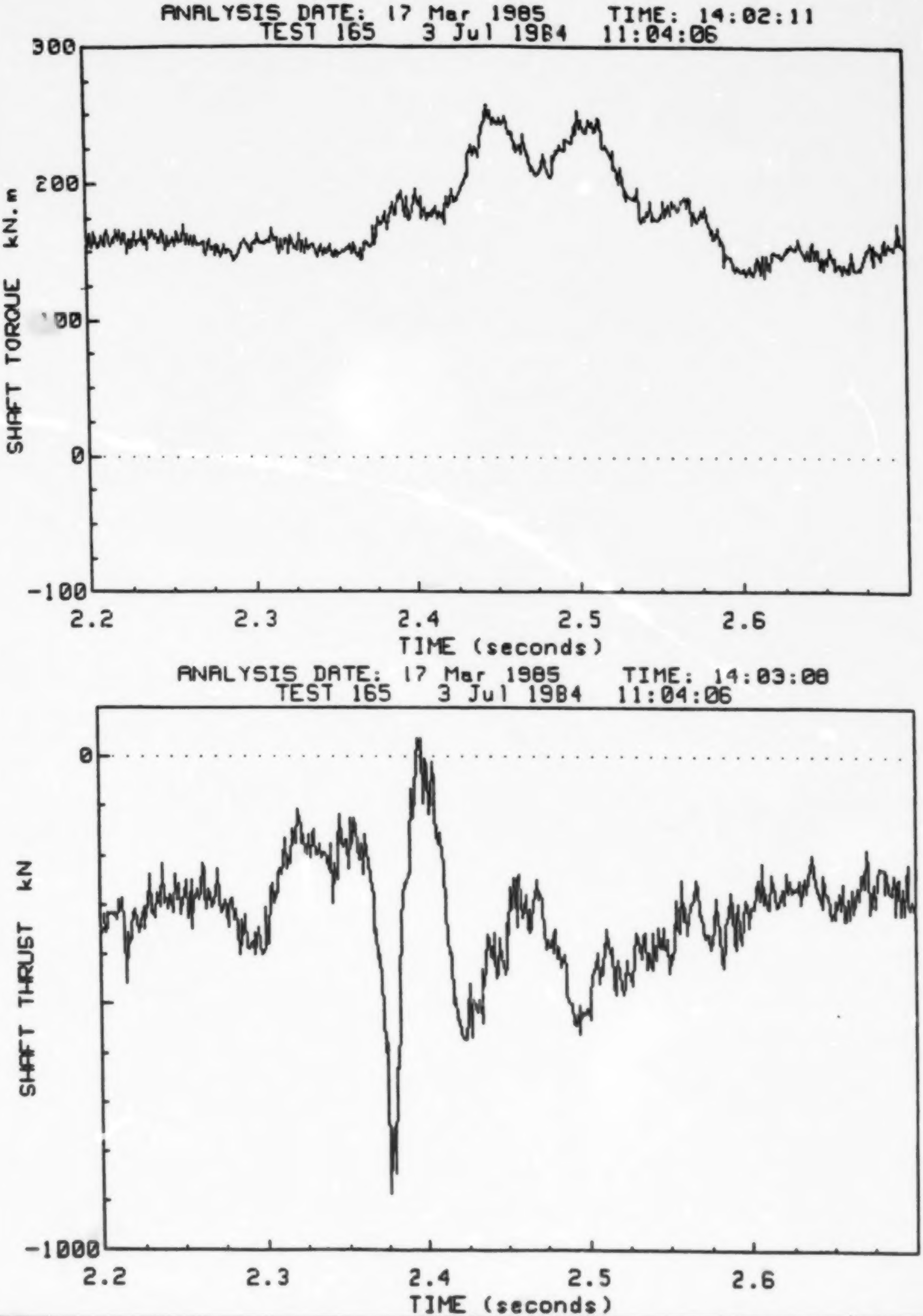
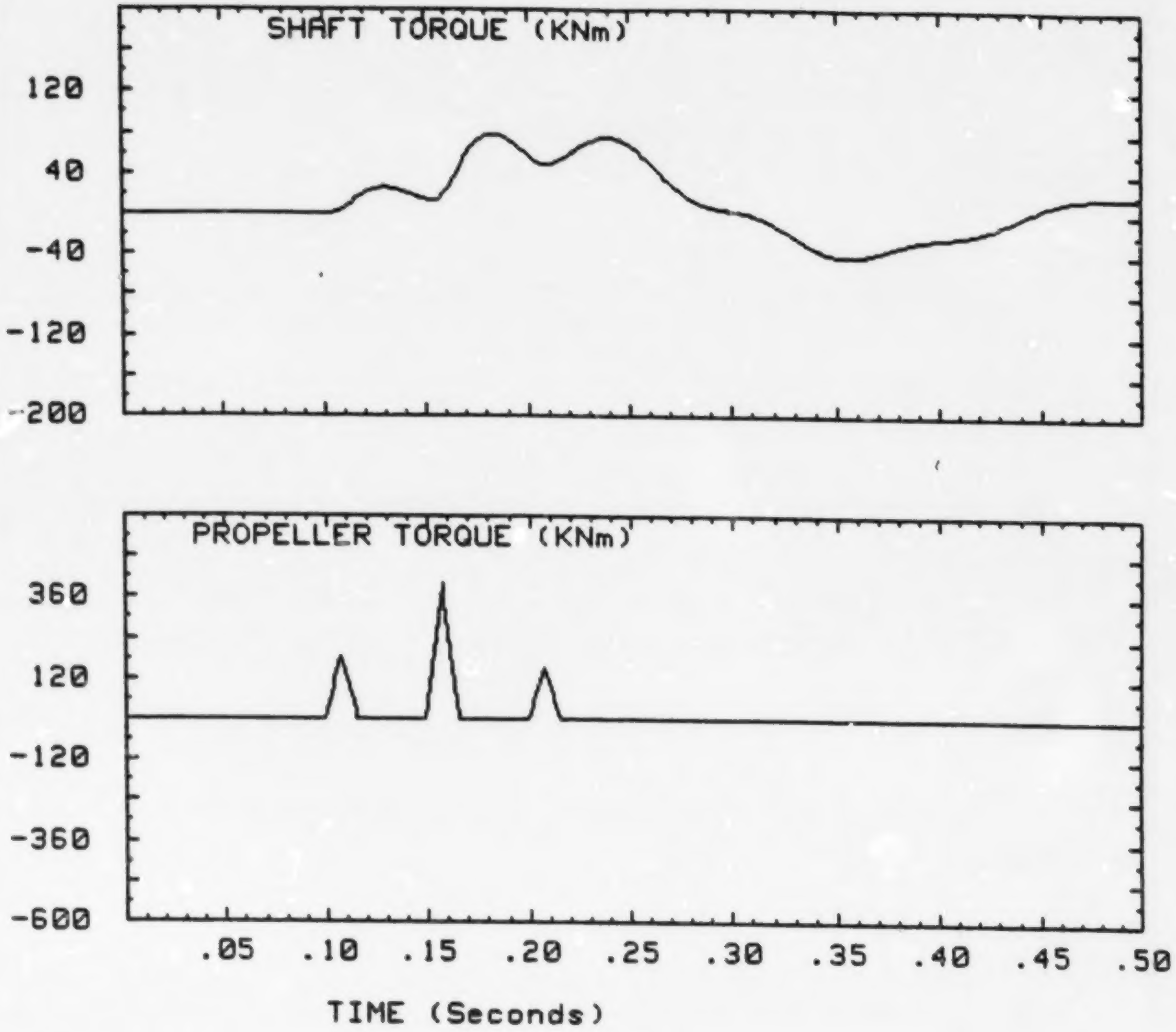
PARAMETERS

TITLE: EFFECT OF SHAPE AND IMPACT DURATION ON TORQUE RESPONSE OF SHAFT

TABLE 4.9.3-2



CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: MEASURED TORQUE AND THRUST SHORT DURATION RESPONSE FOR TEST 165 FIGURE No. 4.9.3-3



DAMPING RATIO FOR THE SHAFT: .08
DAMPING RATIO FOR THE PROPELLER: .1
TIME INCREMENT (SEC.): .001
TIME AT FIRST IMPULSE (SEC.): .1
LENGTH OF FIRST IMPULSE (SEC.): .016 MAX. TORQUE (KNm): 185
TIME AT SECOND IMPULSE (SEC.): .15
LENGTH OF SECOND IMPULSE (SEC.): .016 MAX. TORQUE (KNm): 400
TIME AT THIRD IMPULSE (SEC.): .2
LENGTH OF THIRD IMPULSE (SEC.): .016 MAX. TORQUE (KNm): 150

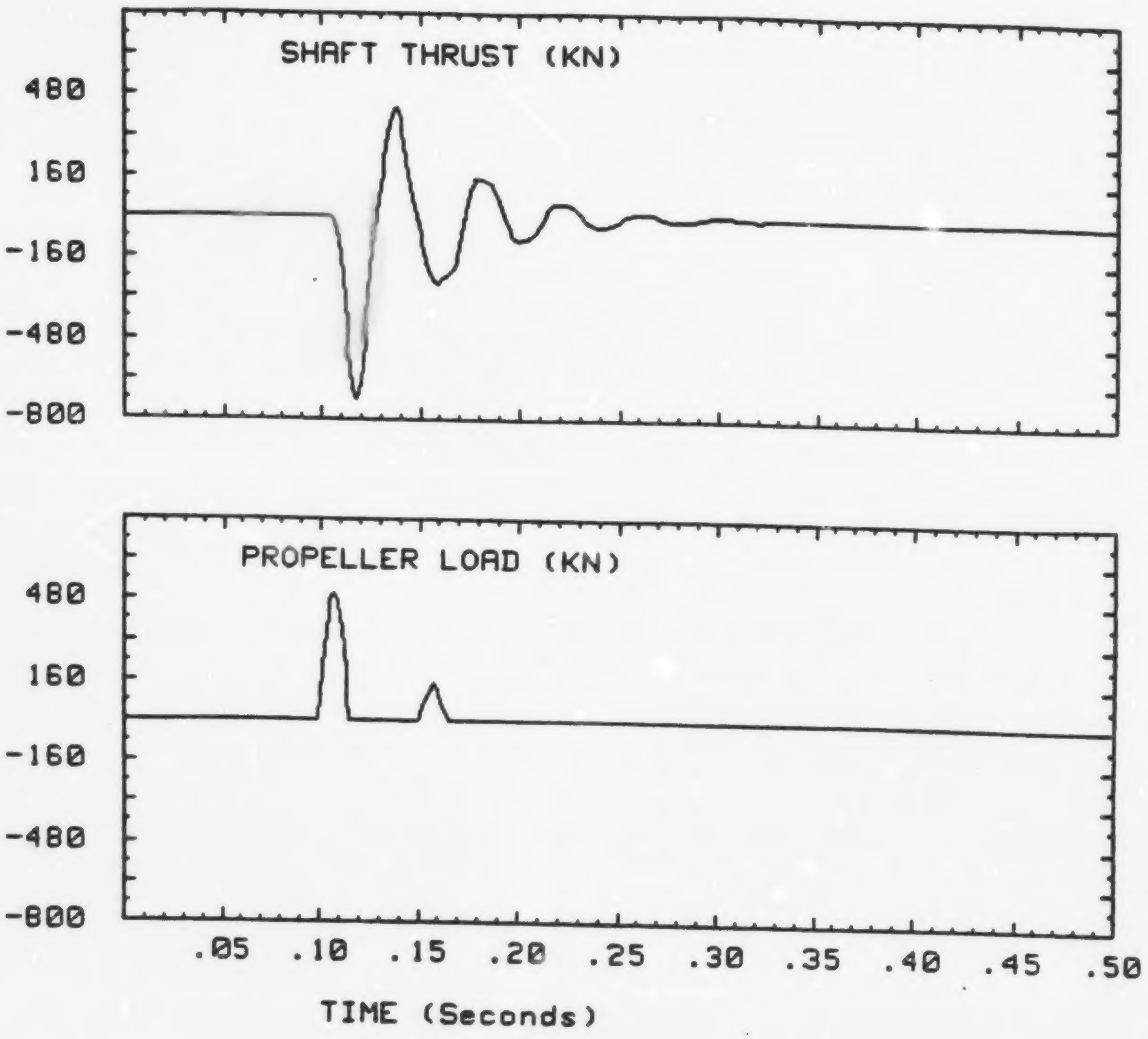
CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
MODEL TORQUE RESPONSE FOR TEST 165

FIGURE No. 4.9.3-4

TEST 165
ANALYSIS DATE: 84/10/30



DAMPING COEFFICIENT FOR SHAFT:	.08		
DAMPING COEFFICIENT FOR PROP.:	.08		
TIME INCREMENT:	.001		
TIME AT FIRST IMPULSE (SEC.)	.1		
LENGTH OF FIRST IMPULSE (SEC.)	.016	MAX. PROPELLER LOAD (KN):	500
TIME AT SECOND IMPULSE (SEC.)	.15		
LENGTH OF SECOND IMPULSE (SEC.)	.016	MAX. PROPELLER LOAD (KN):	150

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: MODEL THRUST RESPONSE FOR TEST 165

FIGURE No. 4.9.3-5

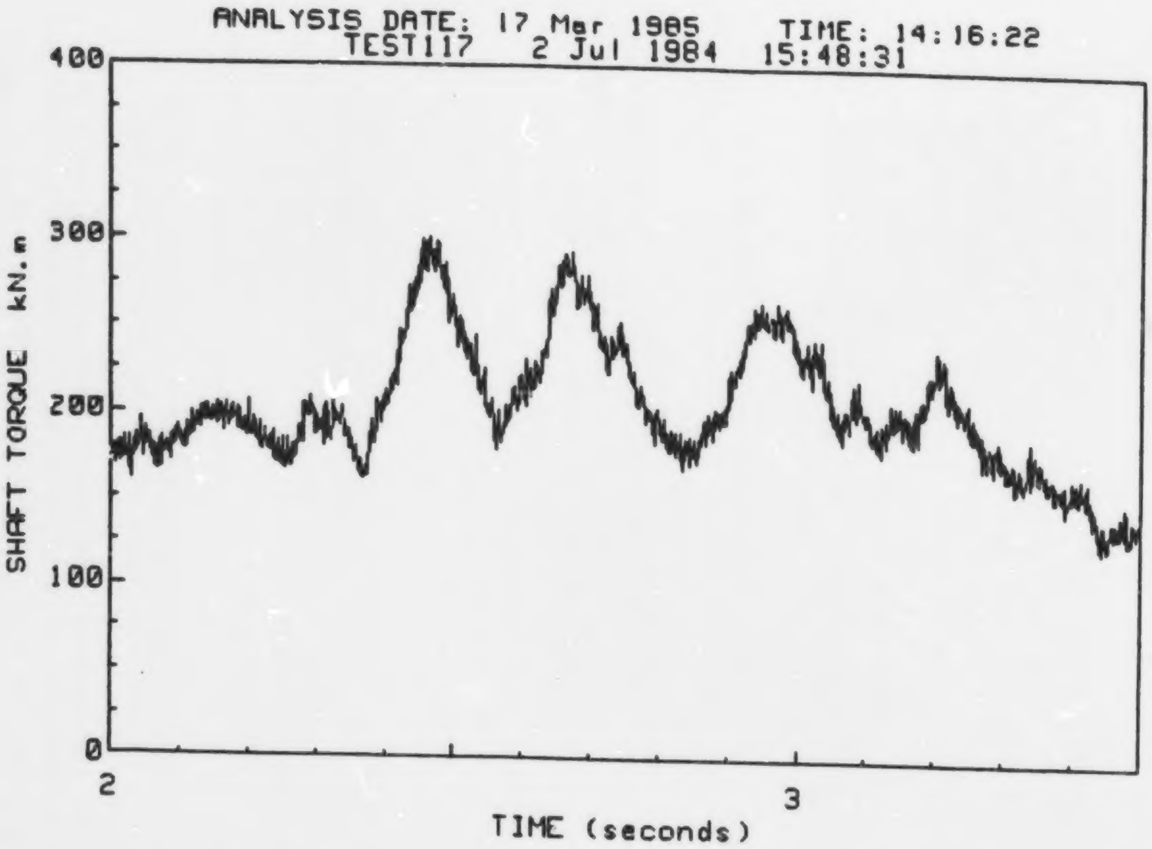
The measured torque on the propeller shaft during a milling event is shown in Figure 4.9.3-6 (Test 117). The estimated change in propeller torque from the mean level is shown in Figure 4.9.3-7. The milling lasted for approximately one second during which time the load on the propeller blades increased in duration and decreased in magnitude. The data for the input propeller torque is listed on Table 4.9.3-3.

The measured torque and thrust loads on the propeller shaft for a series of short duration impact are shown in Figure 4.9.3-8 (Test 72). The variation from the mean torque and thrust, and the calculated responses are shown in Figure 4.9.3-9 and Figure 4.9.3-10 respectively. The specifications for the input loads to the model for this event are listed in Table 4.9.3-4. The first two impacts provided a negative propeller thrust component (axial load towards the aft), and a positive propeller torque component. The subsequent impacts had large positive torque and thrust components.

The measured torque response for a blockage and subsequent impact event is shown in Figure 4.9.3-11 (Test 336). The estimated torque variation and the calculated response are shown in Figure 4.9.3-12 and the specifications for the model are listed in table 4.9.3-5. There was an initial decrease in torque, possibly caused by a hydrodynamic variation due to blockage, which remained constant throughout the event. Impacts on the propeller caused large increases in the shaft torque throughout the event.

4.9.4 Conclusions

- The models developed were a reasonable representation of the real system. The predicted peak shaft torque and thrust torque response are within 15% of the measured values (Test 165).
- The models were a useful tool in helping to estimate the magnitude of ice loads on the propeller (Test 165).
- The models helped determine the number of blades that hit the ice, and the type of event that occurred. (Test 165, Test 72)
- Using the models and shaft measurements in lieu of blade measurements, in the determination of ice loading on the propulsion train components, appears to be feasible. The following must be done to substantiate the above:



CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
SHAFT TORQUE DURING MILLING TEST 117

FIGURE No. 4.9.3 - 6

```
PLOTS OF TORQUE  FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM MODEL


TEST 117
ANALYSIS DATE: 85/03/11


DAMPING RATIO  FOR THE SHAFT:      .08
DAMPING RATIO  FOR THE PROPELLER:  .1
TIME INCREMENT (SEC.):             .01
TIME AT FIRST IMPULSE (SEC.):      .3
LENGTH OF FIRST IMPULSE (SEC.):    .1   MAX. TORQUE (KNm):  90
TIME AT SECOND IMPULSE (SEC.):     .47
LENGTH OF SECOND IMPULSE (SEC.):   .17   MAX. TORQUE (KNm):  75
TIME AT THIRD IMPULSE (SEC.):      .7
LENGTH OF THIRD IMPULSE (SEC.):    .2   MAX. TORQUE (KNm):  57
TIME AT FOURTH IMPULSE (SEC.):      .95
LENGTH OF FOURTH IMPULSE (SEC.):    .07   MAX. TORQUE (KNm):  40
TIME AT FIFTH IMPULSE (SEC.):      1.05
LENGTH OF FIFTH IMPULSE (SEC.):    .1   MAX. TORQUE (KNm):  40
```

CANADIAN
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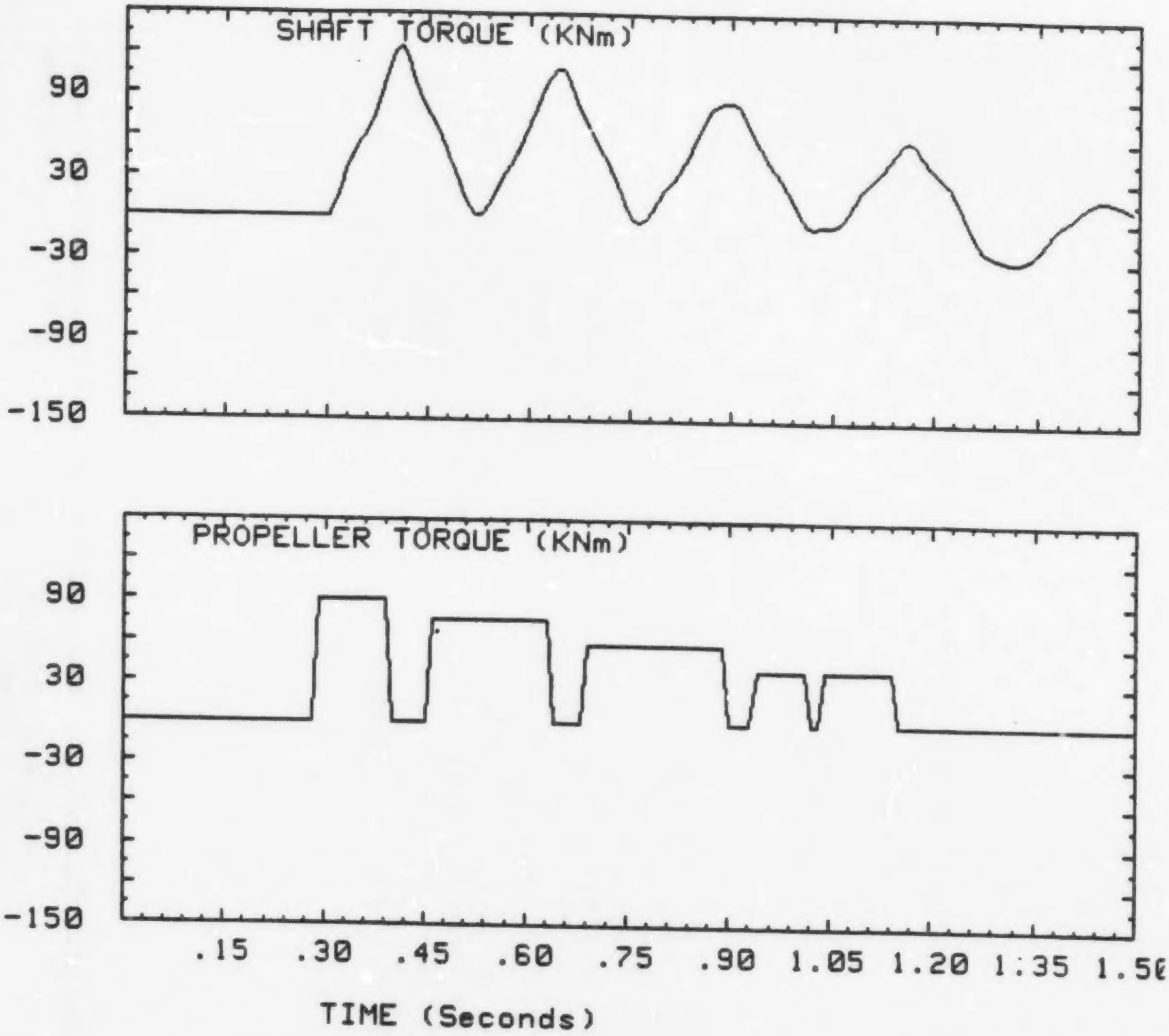
LIMITED

MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE: DATA FOR IMPACT PROPELLER TORQUE
TEST 117

TABLE 4.9.3-3

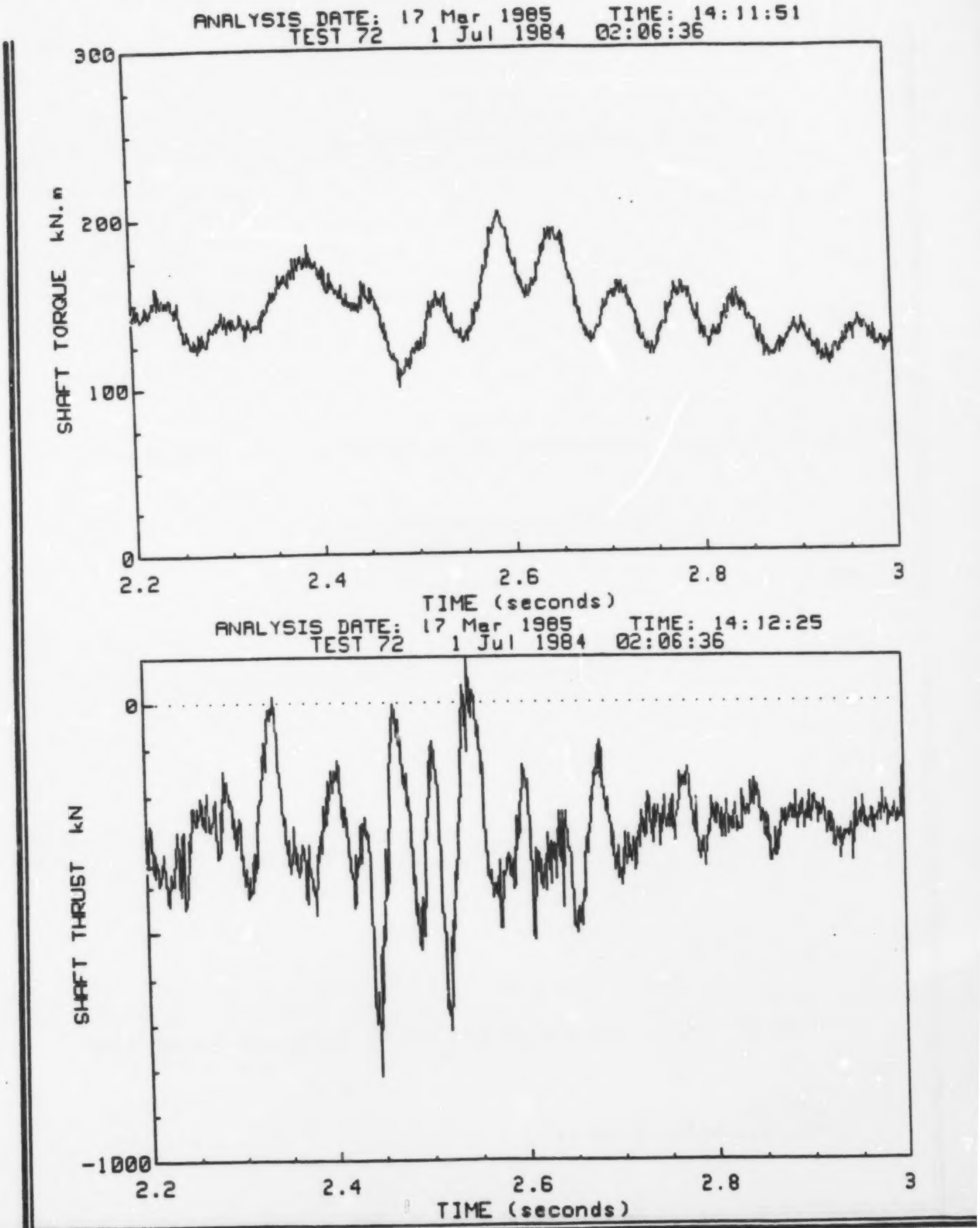


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
ESTIMATED CHANGE IN PROPELLER TORQUE FOR TEST 117

FIGURE No. 4.9.3-7

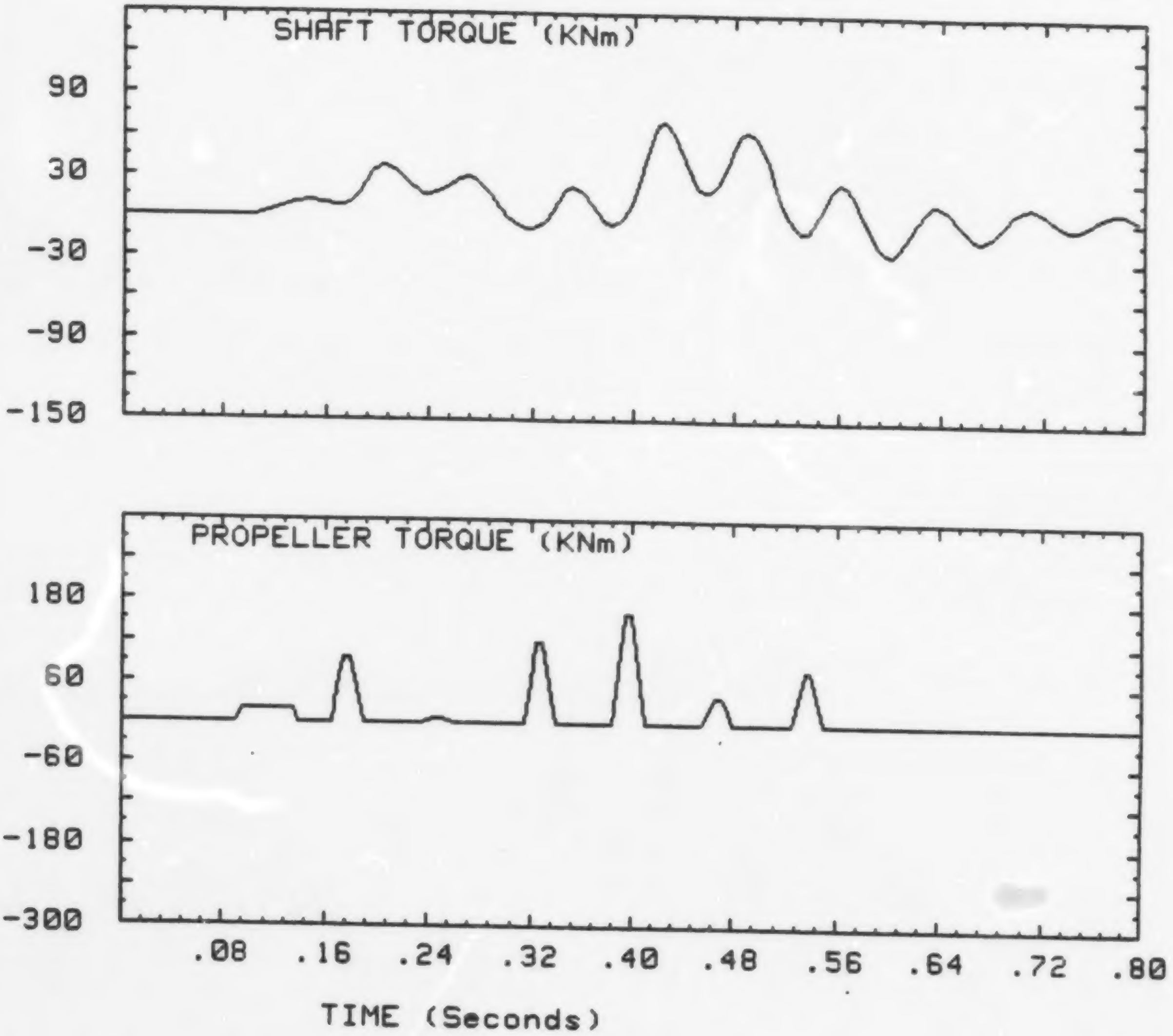


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
MEASURED TORQUE AND THRUST FOR
SERIES OF SHORT IMPACTS, TEST 72

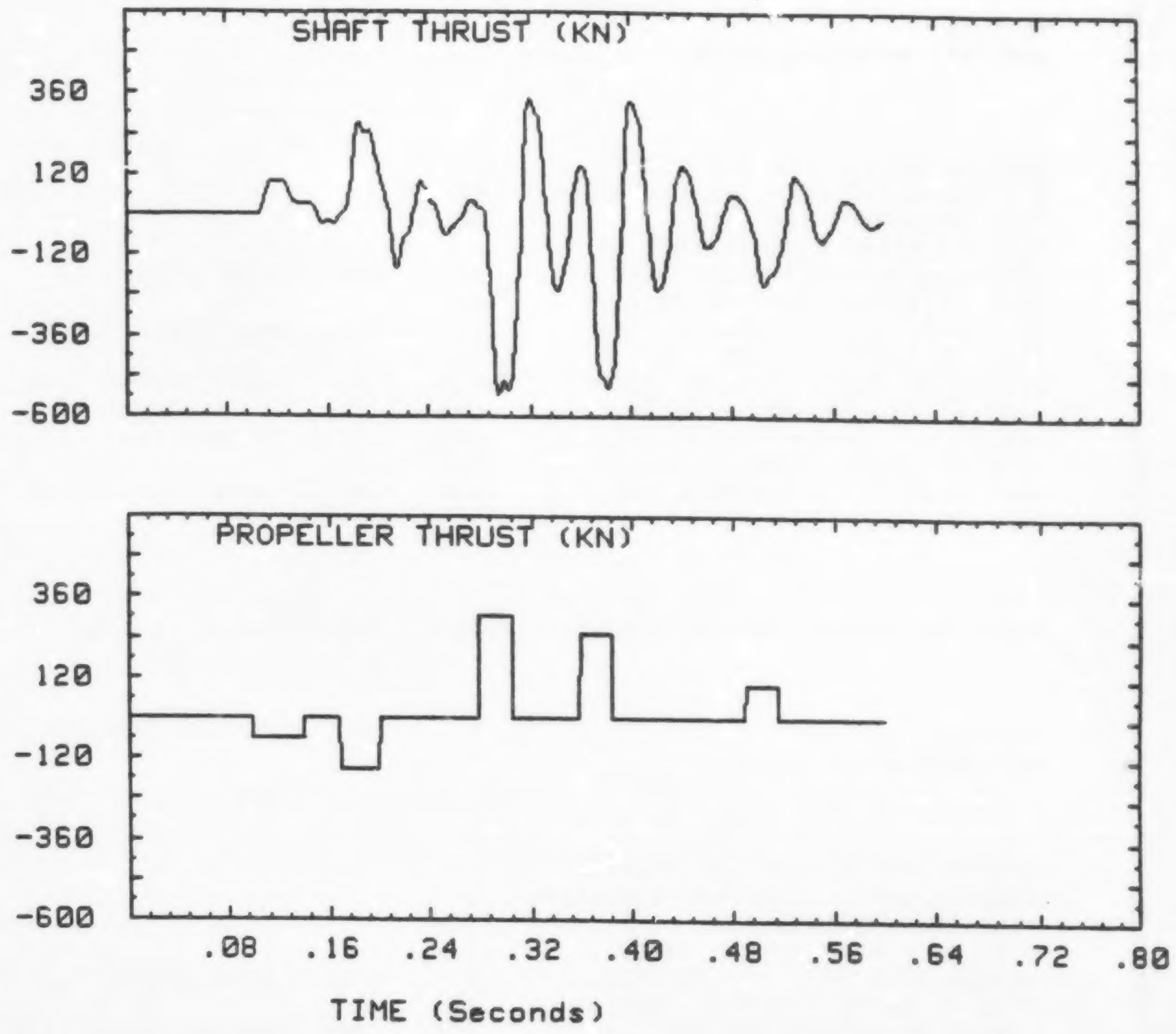
FIGURE No. 4.9.3-8



PLOTS OF TORQUE FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM MODEL

TEST 72
ANALYSIS DATE: 85/03/13

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: CALCULATED TORQUE RESPONSE FOR A SERIES OF SHORT IMPACTS, TEST 72** **FIGURE No. 4.9.3-9**



PLOTS OF THRUST FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM MODEL

TEST 72
ANALYSIS DATE: 85/03/14

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: CALCULATED THRUST RESPONSE FOR A SERIES OF SHORT IMPACTS, TEST 72** **FIGURE No. 4.9.3-10**

```
PLOTS OF THRUST  FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM MODEL


TEST 72
ANALYSIS DATE: 85/03/14


DAMPING RATIO  FOR THE SHAFT:        .055
DAMPING RATIO  FOR THE PROPELLER:    .08
TIME INCREMENT (SEC.):               .001
TIME AT FIRST IMPULSE (SEC.):        .1
LENGTH OF FIRST IMPULSE (SEC.):      .04    MAX. THRUST (KN): -60
TIME AT SECOND IMPULSE (SEC.):       .17
LENGTH OF SECOND IMPULSE (SEC.):     .03    MAX. THRUST (KN): -150
TIME AT THIRD IMPULSE (SEC.):        .28
LENGTH OF THIRD IMPULSE (SEC.):      .025    MAX. THRUST (KN):  300
TIME AT FOURTH IMPULSE (SEC.):        .36
LENGTH OF FOURTH IMPULSE (SEC.):      .025    MAX. THRUST (KN):  250
TIME AT FIFTH IMPULSE (SEC.):        .49
LENGTH OF FIFTH IMPULSE (SEC.):      .025    MAX. THRUST (KN):  100
```

```
PLOTS OF TORQUE  FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM MODEL


TEST 72
ANALYSIS DATE: 85/03/13


DAMPING RATIO  FOR THE SHAFT:        .08
DAMPING RATIO  FOR THE PROPELLER:    .1
TIME INCREMENT (SEC.):               .005
TIME AT FIRST IMPULSE (SEC.):        .1
LENGTH OF FIRST IMPULSE (SEC.):      .04    MAX. TORQUE (KNm):  20
TIME AT SECOND IMPULSE (SEC.):       .17
LENGTH OF SECOND IMPULSE (SEC.):     .025    MAX. TORQUE (KNm):  120
TIME AT THIRD IMPULSE (SEC.):        .24
LENGTH OF THIRD IMPULSE (SEC.):      .025    MAX. TORQUE (KNm):  10
TIME AT FOURTH IMPULSE (SEC.):        .32
LENGTH OF FOURTH IMPULSE (SEC.):      .025    MAX. TORQUE (KNm):  150
TIME AT FIFTH IMPULSE (SEC.):        .39
LENGTH OF FIFTH IMPULSE (SEC.):      .025    MAX. TORQUE (KNm):  200
TIME AT SIXTH IMPULSE (SEC.):        .46
LENGTH OF SIXTH IMPULSE (SEC.):      .025    MAX. TORQUE (KNm):  50
TIME AT SEVENTH IMPULSE (SEC.):        .53
LENGTH OF SEVENTH IMPULSE (SEC.):      .025    MAX. TORQUE (KNm):  100
```

**CANADIAN
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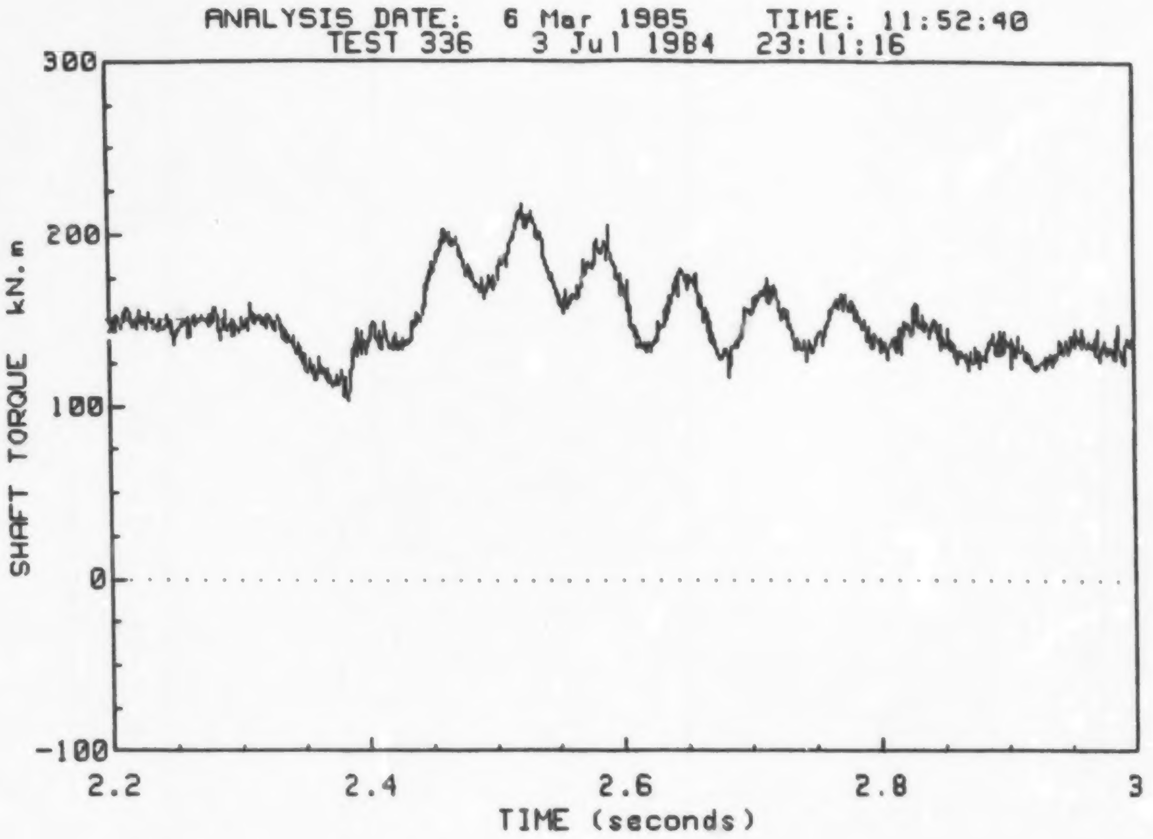
**MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS**

TITLE:
**SPECIFICATIONS FOR INPUT
LOADS, TEST 72**

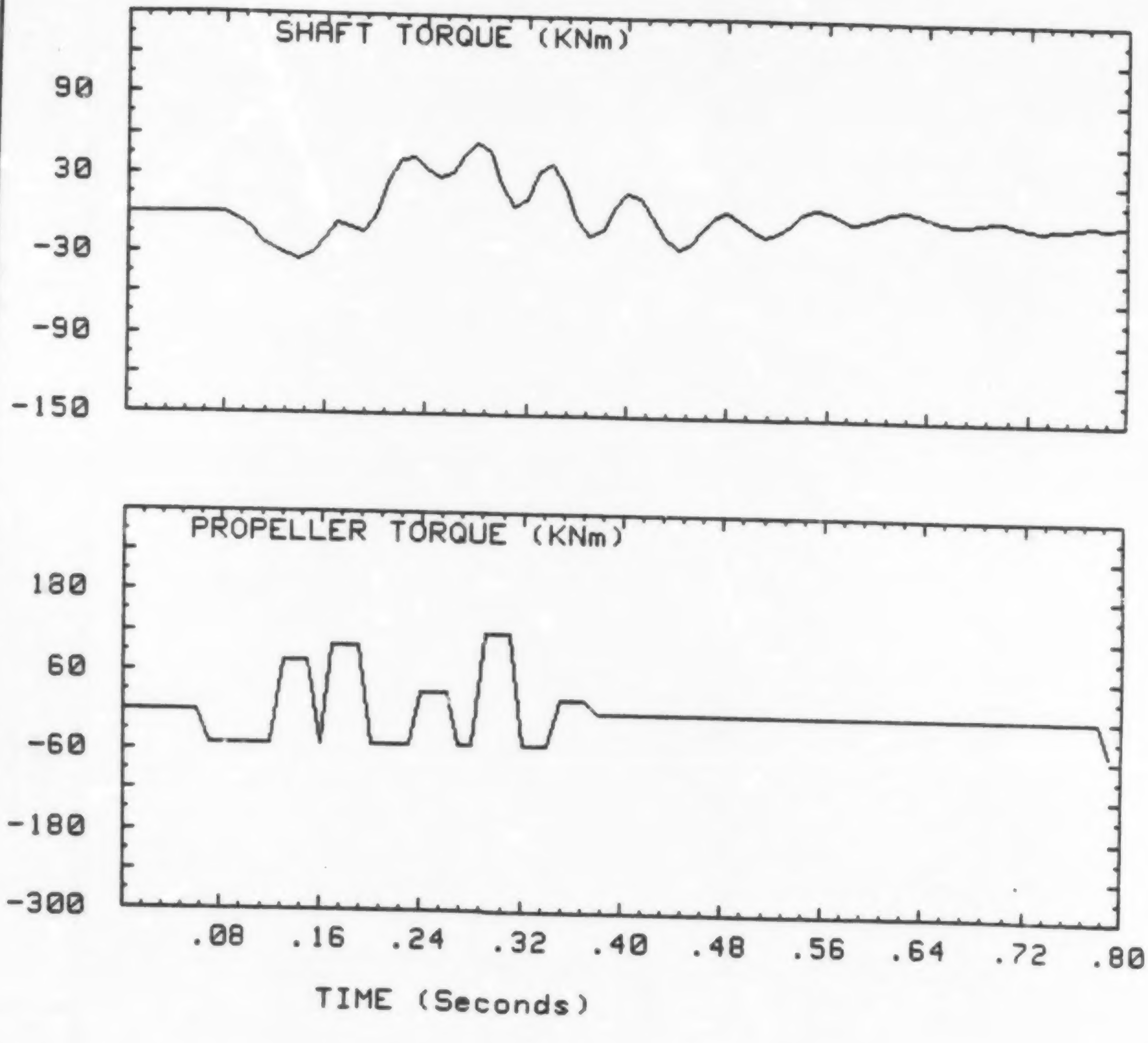
TABLE 4.9.3-4



CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: MEASURED SHAFT TORQUE FOR BLOCKAGE, TEST 336 FIGURE No. 4.9.3-11

PLOTS OF TORQUE FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM MODEL

TEST 336
ANALYSIS DATE: 85/03/13



CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: ESTIMATED TORQUE VARIATION AND CALCULATED RESPONSE FOR BLOCKAGE, TEST 336**
		FIGURE No. 4.9.3-12

```
PLOTS OF TORQUE  FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM MODEL


TEST 336
ANALYSIS DATE: 85/03/13


DAMPING RATIO  FOR THE SHAFT:        .08
DAMPING RATIO  FOR THE PROPELLER:    .1
TIME INCREMENT (SEC.):               .01
TIME AT FIRST IMPULSE (SEC.):        .08
LENGTH OF FIRST IMPULSE (SEC.):      .3   MAX. TORQUE (KNm): -50
TIME AT SECOND IMPULSE (SEC.):       .14
LENGTH OF SECOND IMPULSE (SEC.):     .025   MAX. TORQUE (KNm):  75
TIME AT THIRD IMPULSE (SEC.):        .18
LENGTH OF THIRD IMPULSE (SEC.):      .025   MAX. TORQUE (KNm):  100
TIME AT FOURTH IMPULSE (SEC.):        .25
LENGTH OF FOURTH IMPULSE (SEC.):      .025   MAX. TORQUE (KNm):  30
TIME AT FIFTH IMPULSE (SEC.):        .3
LENGTH OF FIFTH IMPULSE (SEC.):      .025   MAX. TORQUE (KNm):  120
TIME AT SIXTH IMPULSE (SEC.):        .36
LENGTH OF SIXTH IMPULSE (SEC.):      .025   MAX. TORQUE (KNm):  20
```

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: MODEL SPECIFICATIONS FOR BLOCKAGE, TEST 336 TABLE 4.9.3-5

i. A more detailed model should be developed to include: the effects of coupled torsion and flexure and longitudinal vibrations, the effects of machinery parameters (propeller pitch and fuel rack).
ii. The results from the above model should be compared to the existing models.
iii. More analysis should be done on comparing the loads calculated from blade measurements, and loads calculated from the above models.

- During the time period from the start of the response until the peak, both model outputs were approximately the same as the measured response. After this period, various parameters changed (propeller pitch, fuel rack, propeller/ice interaction) resulting in some discrepancy in the last part of the model's response waveform.

4.9.5 Recommendations

It is recommended that the following be implemented:

- The development of more detailed models to incorporate ice-propeller interaction and machinery parameters. These models should eliminate the approximations made with the existing models, and be made general enough for applications to other vessels.
- A statistical analysis be preformed on the thrust and torque estimates from the above models.
- A series of propeller torque and thrust wave forms during ice interaction be generated for design purposes.
- A study be done on incorporating mathematical models that predict propeller loads from shaft measurements, for use in regulations and preventative maintenance programs, for propulsion systems operating in ice.

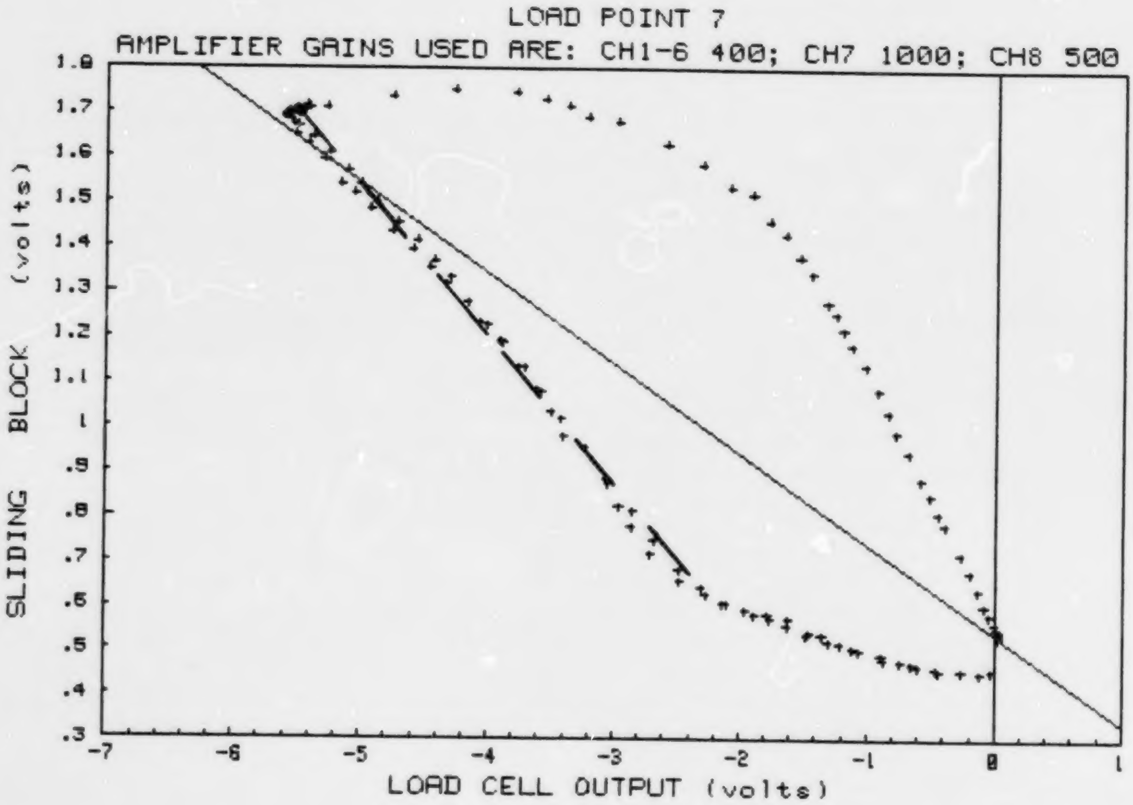
4.10 Calibration Factor for Yoke Pin Sliding Block

The calibration of the sliding block at the University of Calgary was covered in Section 4 of Milestone 1 while the yoke pin model was covered in Section 9 of Milestone 1. The calibration of the sliding block at the University of Calgary yielded a calibration factor for the full bridge configuration of 122.2 kN/V at an amplifier gain of 1,000. This same gain was always used for the sliding block signal. The calibration factor of 122.2 kN/V was used for the sliding block data during initial data analysis. However, the results given by this calibration factor did not match other signal data such as blade spindle torque and servo oil pressure. Problems had also been noted during the initial calibration at the University, such as the dependence of the measured outputs, on the orientation and assembly of the sliding block/pin jig. For these reasons, it was decided to determine the calibration factor of the sliding block, based on data gathered after the hub was reassembled. This method of calibration had the disadvantage that friction in the sliding block system could not be accounted for. Since the friction was unknown it was assumed equal to zero.

The data used to calibrate the sliding block signal for data analysis, was from the static calibrations performed on the Wurmlinger drydock. The static calibrations are covered in Sections 3 and 4 of Milestone 1. A sample sliding block calibration is given in Figure 4.10-1. This shows the hysteresis in the output signal, which was noted in all of the Wurmlinger calibrations. The program used to collect the static calibration data and plot the output is "HSDAR4_5", listed in Appendix A.

The lozenge shape shown in Figure 4.10-1 is due to friction between the parts of the pitch change mechanism. The sides of the figure are essentially parallel in all cases. When the load is increased and decreased, the signal from the sliding block follows the slope of the four sides, as long as the applied load is large enough to cause the signal to rise to the level shown by the dashed line. The output signal will remain essentially linear along the dashed line, as long as the load is increasing. When the load starts to decrease, the signal follows a path parallel to the top horizontal line until it reaches the line parallel to the dashed line. The signal will then return by this line to approximately where the signal was before the load was applied.

The difference between the starting point, and the end point is due to friction locking in stresses in the system. Since the signal follows the dashed line during increasing loads, the slope of this line was choosen to calculate the calibration constant. The slope of the dashed line is different than the slope of the solid line, which is the "least square" fit for all data points. Since the sliding block signal follows the slope of the dashed line, once the load is large enough, only those calibrations in which the load on the sliding block was large enough to cause the signal to follow this line were



TITLE: SLIDING BLOCK WURMLINGER CALIBRATION, LOAD POINT 7, CASE 4

FIGURE No. 4.10-1

used. These measured slopes were then compared with calculated slopes for each of the load points which had data available. The theoretical outputs, neglecting friction, were calculated using the program "BLADE-CAL3" given in Appendix A.

In order to determine the true sliding block calibration, the slopes of Sliding Block Force/Applied Force, (represented by the dashed line in Figure 4.10-1, were plotted against the theoretical Sliding Block Force/Applied Force. There were a total of 28 static calibrations in which the applied load was large enough to measure the slope of the dashed line.

It was found that the calibration constant for each side of the sliding block was roughly linear, but that there was a different calibration constant for each side of the sliding block. The sliding block calibrations were found to be 178 kN/V for negative output voltages and 48.8 kN/V for positive output voltages, (i.e. opposite sides of the sliding block).

The good agreement of the calculated and measured slopes is shown in Figure 4.10-2. This calibration is only for the full bridge configuration of the sliding block. During the actual test period, the sliding block strain gauges were half and quarter bridges. As a first approximation, the calibration constants for the half and quarter bridge configurations were choosen as twice the full bridge values. However, when these gains were used to compare sliding block loads to servo oil pressure and blade spindle torques, the calibration constant for the negative sliding block signal, during the half bridge tests, were found to be 10 times too large. Therefore, the sliding block calibrations for the half and quarter bridge configurations during the ship testing period are assumed to be: 35.6 kN/V for negative output voltages; and; 97.6 kN/V for positive output voltages.

The calibration constant for the negative sliding block signal may have been off due to the differences in the gauge installations on each side of the sliding block. In any event, since this calibration constant had to be divided by 10, and the results from this side of the sliding block are not as accurate as the results from the positive sliding block forces, the loads measured on the negative side of the sliding block are given a low level of confidence.

In order to check the accuracy of the sliding block calibration constants, and to show how this signal is related to servo oil pressure and blade spindle torque, comparisons of these three signals are given in Figures 4.10-3 to 4.10-11.

Comparisons of the measured versus theoretical transfer functions between these 3 signals are given in Table 4.10-1. The theoretical transfer functions were calculated assuming equal loading on all four sliding blocks, no friction in the system, and the propeller at full ahead pitch.

4.10.1 Assessment of Yoke Pin Model

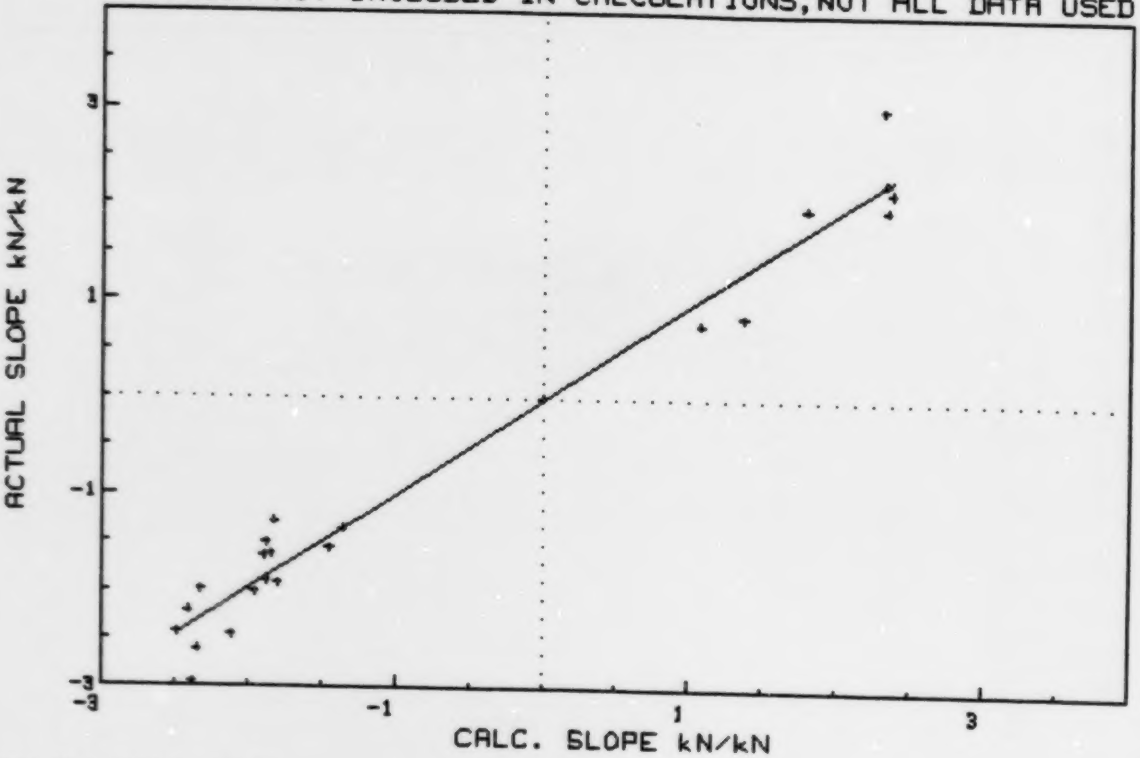
The assessment of the yoke pin model is important to check two things: Firstly whether sensors easily placed inside the ship, such as shaft torque, shaft thrust and servo oil pressure, can be used to measure the phenomena occurring at the propeller, and; whether the assumption that internal friction in the hub reduces the load on the sliding block to approximately one half the value expected, under frictionless conditions, is correct.

The only internal sensor which will be compared to a blade signal in this section, is the servo oil pressure sensor, versus spindle torque and sliding block force.

Figure 4.10-3 shows that the transfer function of Minimum Servo Oil Pressure/Maximum Sliding Block Force, is approximately one quarter of the theoretical value as listed in Table 4.10-1. This is because during an ice-propeller interaction, generally only one blade at a time interacts with the ice, therefore the servo oil pressure does not result in equivalent sliding block loads for all blades.

The transfer function shown in Figure 4.10-4 of the Maximum Sliding Block Forces Versus Maximum Blade Spindle Torque compares with the theoretical value listed in Table 4.10-1. This is because each sliding block responds to the spindle torque on that particular blade. As will be shown later in this section; the friction between the blade carrier and hub reduces the load on the sliding block to approximately 90 per cent of the theoretical value which neglects friction.

CALIBRATION OF SLIDING BLOCK
FRICTION NOT INCLUDED IN CALCULATIONS, NOT ALL DATA USED



```
NOT ALL DATA USED

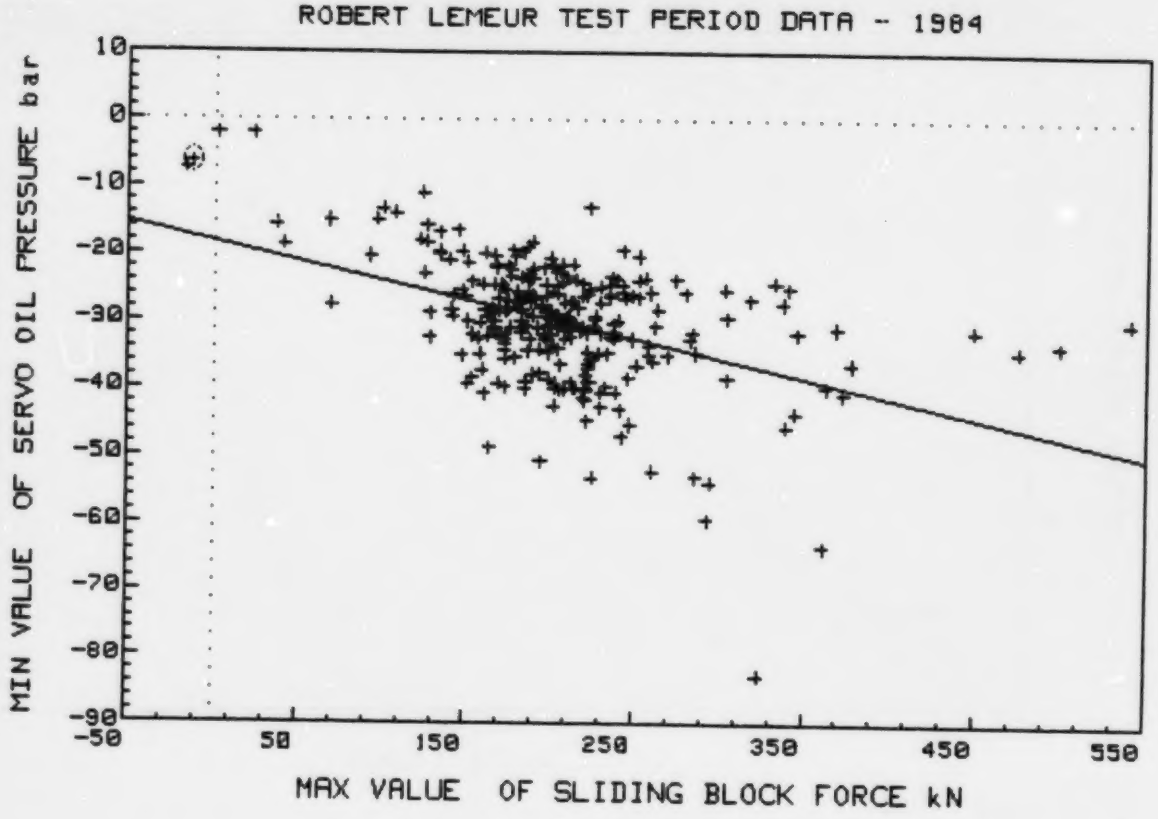
                    DATA POINT NUMBERS USED

 1 , 2 , 3 , 4 , 5 , 6 , 10 , 11 , 12 , 13 , 14 , 15 , 16 , 24 , 25 , 26 , 27 ,
 28 , 29 , 31 , 32 , 33 , 34 , 42 , 43 , 48 , 49 , 50 ,

FOR SUB SET DATA Y =  .983508659556  *X +-.0144035667829
```

FOR POSITIVE VOLTAGES, SLIDING BLOCK CALIB. = 48.8 kN/V
FOR NEGATIVE VOLTAGES, SLIDING BLOCK CALIB. = 178 kN/V

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: ACTUAL SLIDING BLOCK LOAD/ APPLIED LOAD VERSUS CALCULATED SLIDING BLOCK LOAD/ APPLIED LOAD**
		FIGURE No. 4.10-2



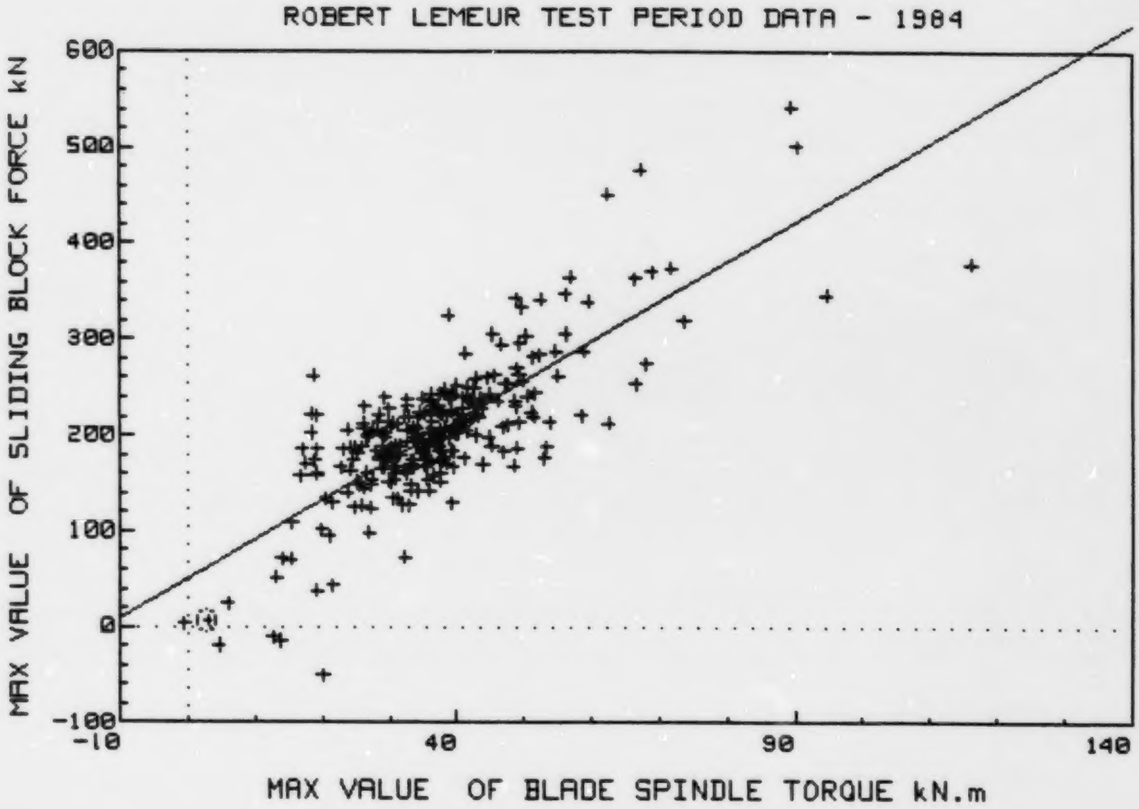
TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 269

NUMBER OF POINTS OUTSIDE PLOTTING AREA IS: 1

ALL DATA USED

Y = -.0580910309213 *X + -18.2858532993

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: MINIMUM SERVO OIL PRESSURE VERSUS MAXIMUM SLIDING BLOCK FORCE**
		FIGURE No. 4.10-3

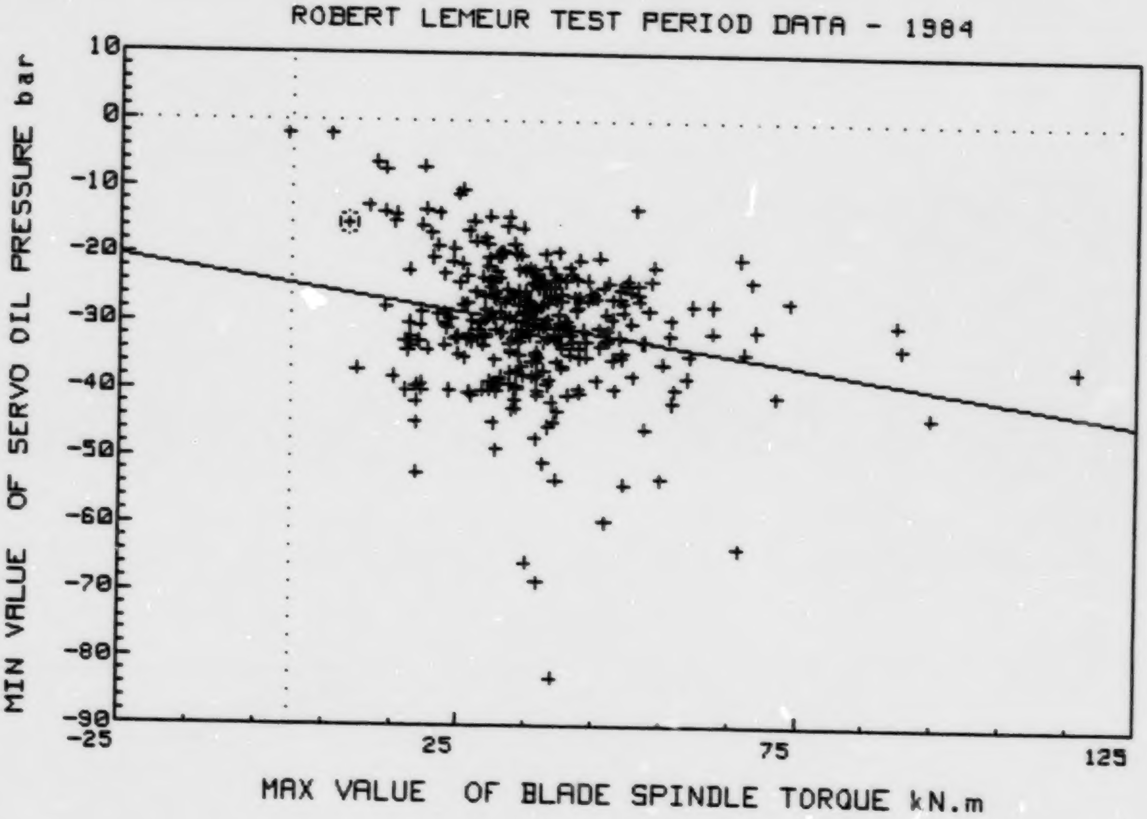


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 273

ALL DATA USED

Y = 4.1270874647 *X + 49.18388799

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	**TITLE:** **MAXIMUM SLIDING BLOCK FORCE VERSUS MAXIMUM BLADE SPINDLE TORQUE**
		FIGURE No. 4.10-4

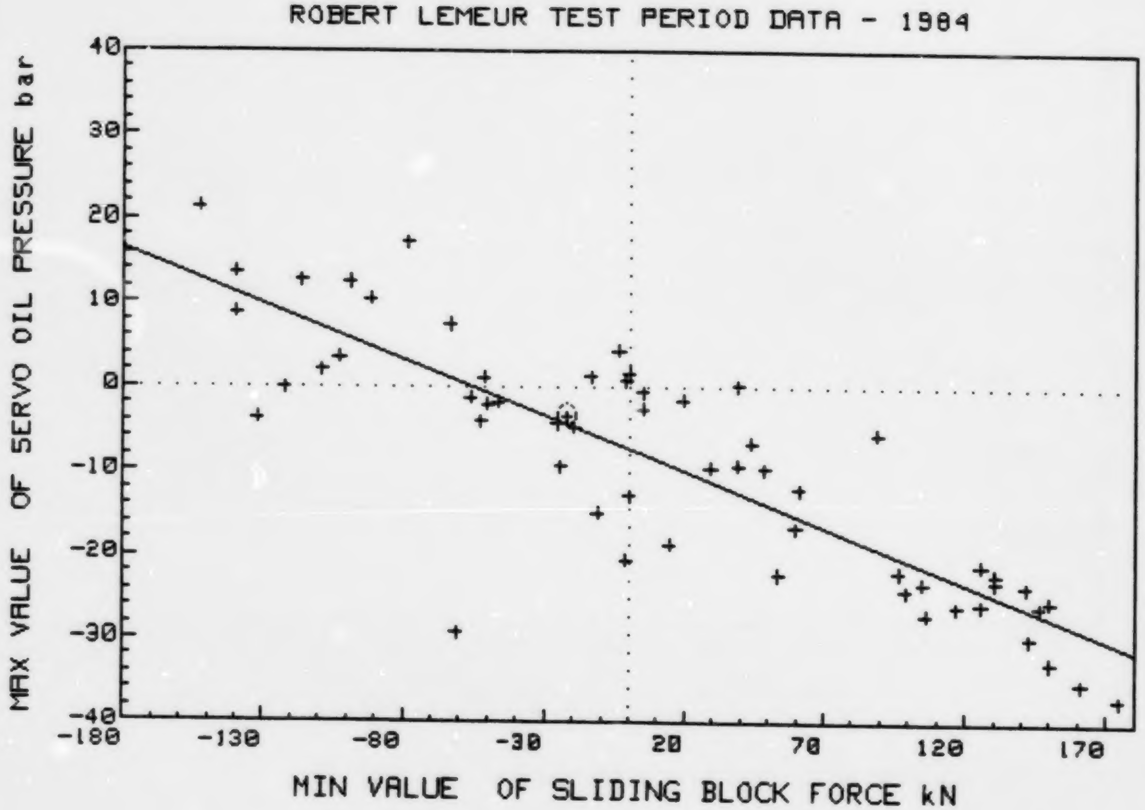


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 336

ALL DATA USED

Y = -.160743457391 *X + -24.275739588

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: MINIMUM SERVO OIL PRESSURE VERSUS MAXIMUM BLADE SPINDLE TORQUE**
		FIGURE No. 4.10-5

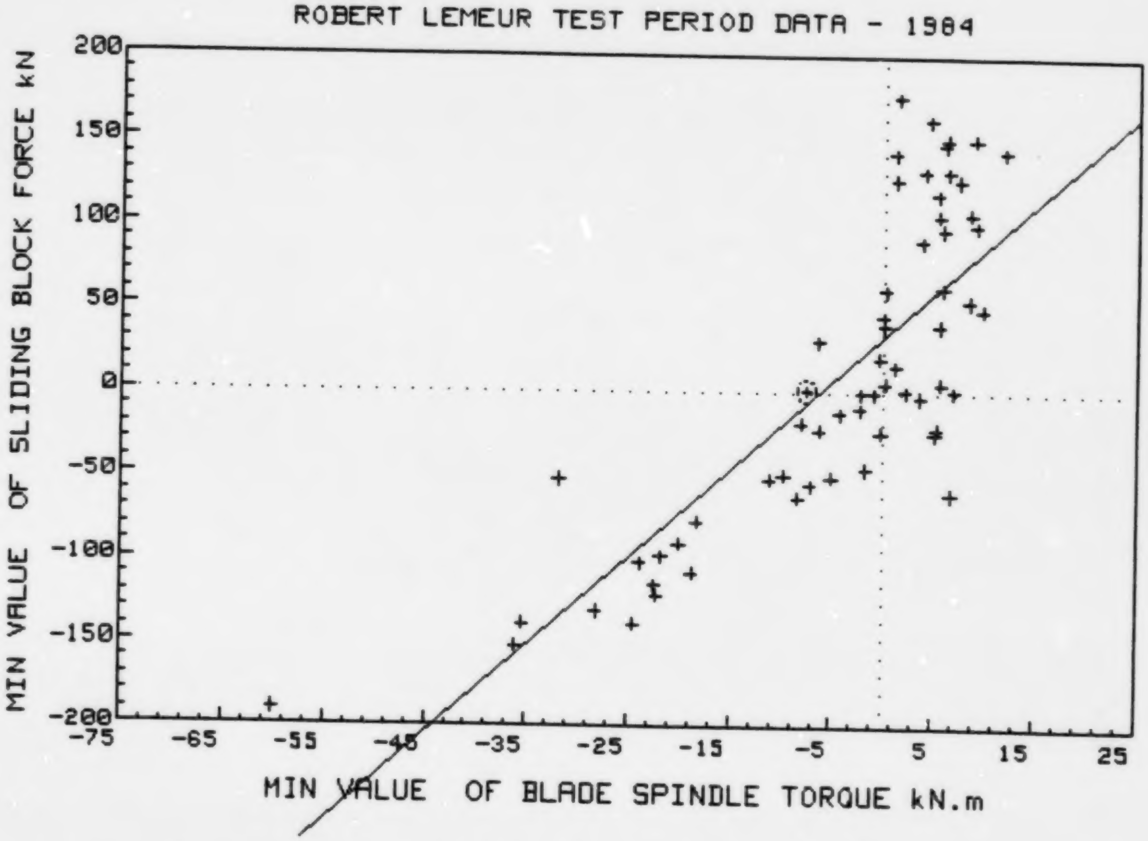


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 58

ALL DATA USED

Y = -.132962889371 *X + -7.45778825431

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE:MAXIMUM SERVO OIL PRESSURE VERSUS MINIMUM SLIDING BLOCK FORCE FIGURE No. 4.10-6

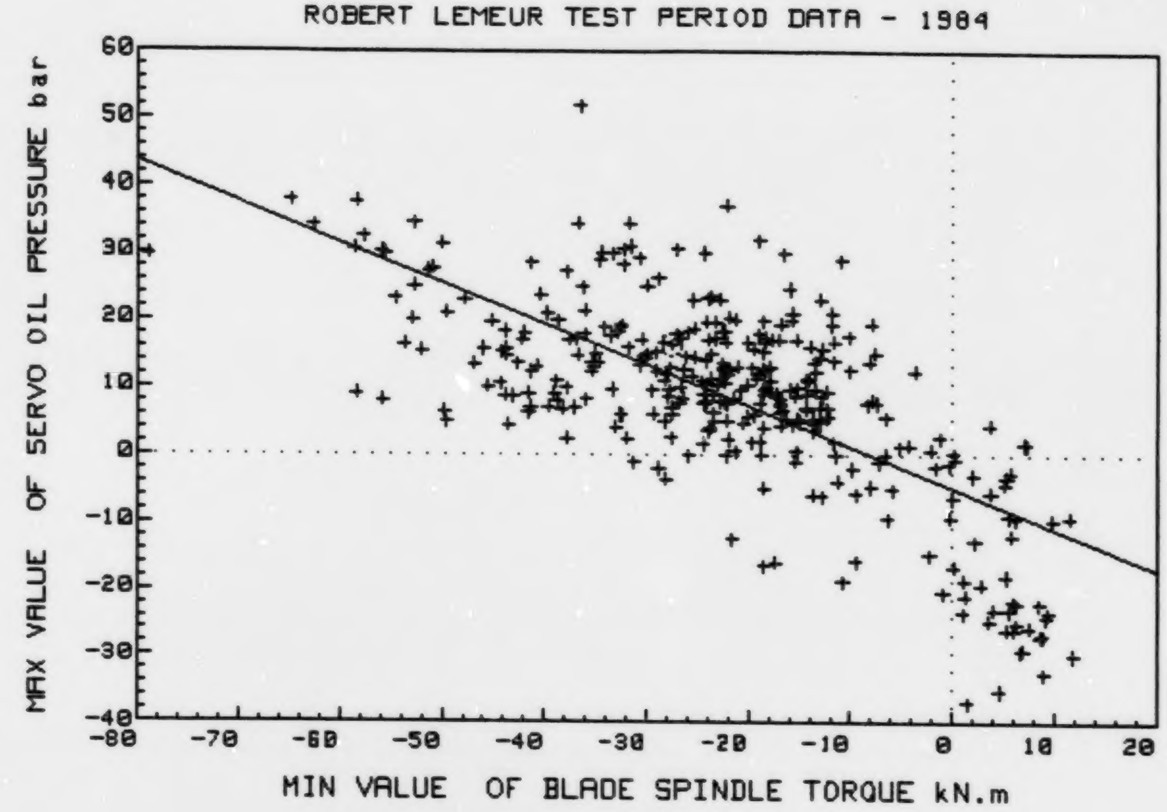


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 62

ALL DATA USED

Y = 5.28324224911 *X + 32.5147422733

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **MINIMUM SLIDING BLOCK FORCES VERSUS MINIMUM BLADE SPINDLE TORQUE**
		FIGURE No. 4.10-7

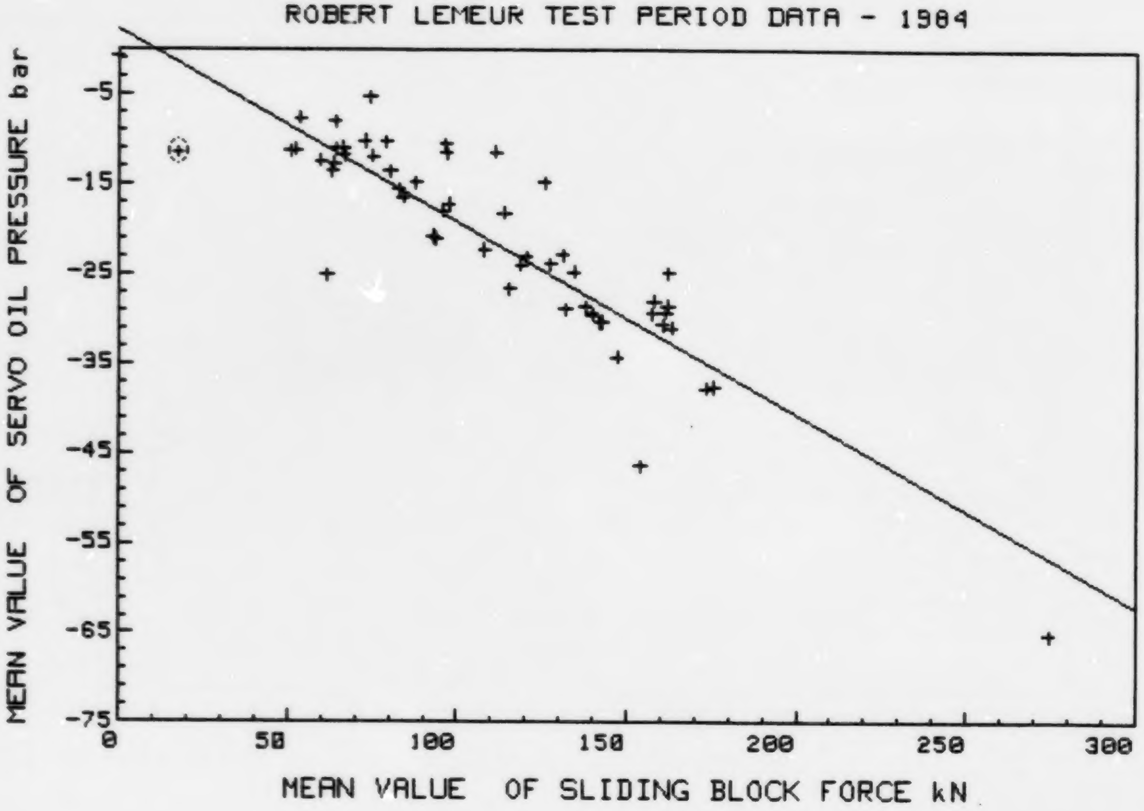


TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 336

ALL DATA USED

Y = -.609466236958 *X + -5.02107635012

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **MAX. VALUE OF SERVO OIL PRESSURE VS MIN. VALUE OF BLADE SPINDLE TORQUE**
		FIGURE No. 4.10-8



```
    TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 55

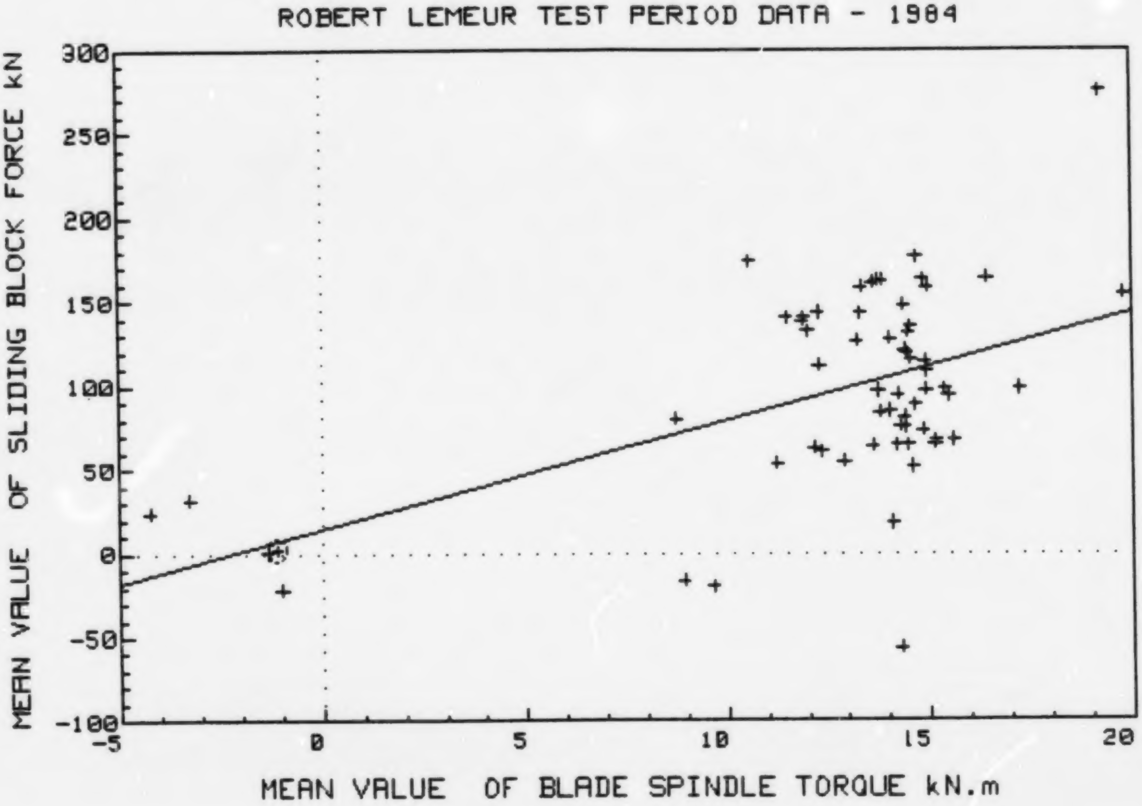
    DATA SATISFIED THE FOLLOWING TEST(S)

    MEAN VALUE  OF SLIDING BLOCK FORCE > 0 kN

Y = -.214367812228 *X +  2.19528992433
```

TITLE:
MEAN SERVO OIL PRESSURE VERSUS MEAN SLIDING BLOCK FORCE

FIGURE No. 4.10-9



```
TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 62

ALL DATA USED

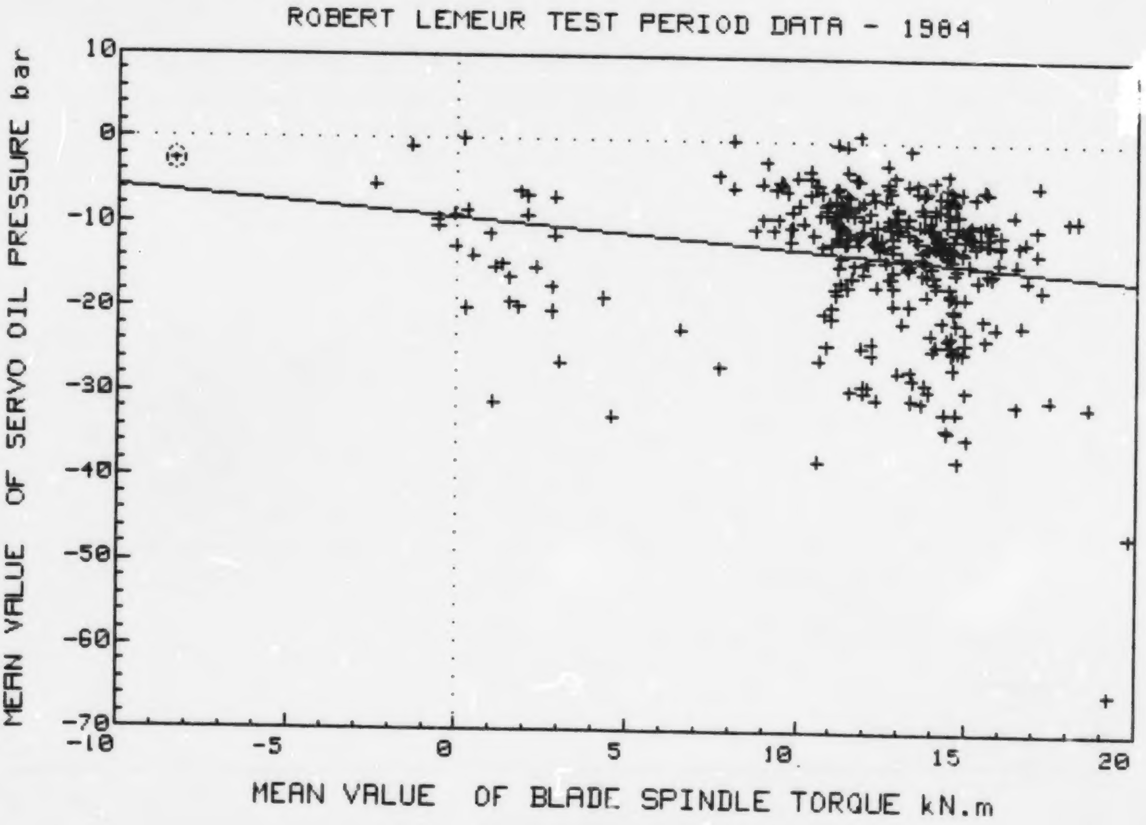
Y =  6.43317991746 *X +  14.3873096604
```

**CANADIAN
MARINE
DRILLING
LIMITED**

**MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS**

**TITLE:
MEAN SLIDING BLOCK FORCE
VERSUS MEAN SPINDLE TORQUE**

FIGURE No. 4.10-10



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 336

ALL DATA USED

Y = -.344892457247 *X + -9.25869318438

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
MEAN SERVO OIL PRESSURE VERSUS MEAN BLADE SPINDLE TORQUE

FIGURE No. 4.10-11

TRANSFER FUNCTION	MEASURED	THEO- RETICAL	UNITS
Minimum Servo Oil Pressure Maximum Sliding Block Force	-0.058	-0.234	bar/kN
Maximum Sliding Block Force Maximum Spindle Torque	4.127	4.474	kN/kN*m
Minimum Servo Oil Pressure Maximum Spindle Torque	-0.161	1.047	bar/kN*m
Maximum Servo Oil Pressure Minimum Sliding Block Force	-0.133	-0.234	bar/kN
Minimum Sliding Block Force Minimum Spindle Torque	5.283	4.474	kN/kN*m
Maximum Servo Oil Pressure Minimum Spindle Torque	-0.609	-1.047	bar/kN*m
Mean Servo Oil Pressure Mean Sliding Block Force	-0.214	-0.234	bar/kN
Mean Sliding Block Force Mean Spindle Torque	6.433	4.474	kN/kN*m
Mean Servo Oil Pressure Mean Spindle Torque	-0.345	-1.047	bar/kN*m

The theoretical transfer functions are based on the following assumptions: No friction; Full ahead pitch, and; Equal blade spindle torque on all blades.

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	MEASURED VERSUS THEORETICAL TRANSFER FUNCTIONS, FOR BLADE SPINDLE TORQUE, SLIDING BLOCK FORCE, AND SERVO OIL PRESSURE
		TABLE 4.10 - 1

Figure 4.10-5 shows the transfer function of Minimum Servo Oil Pressure Versus Maximum Blade Spindle Torque. The theoretical transfer function assumes that all blades experience equal spindle torque at the same instant, however if it is assumed that impacts only occur with one blade at a time, then the servo oil pressure is a result of the spindle torque on one blade, and the theoretical transfer function is:

$$\frac{\text{Minimum Servo Oil Pressure}}{\text{Maximum Blade Spindle Torque}} = -0.2618 \text{ bar/kN.m}$$

This value is still greater than the transfer function shown in Figure 4.10-5 because the internal friction of the hub components reduces the pressure transmitted through the pitch change mechanism to the oil due to peak spindle torques on a single blade.

Figure 4.10-6 shows that the transfer function of Maximum Servo Oil Pressure Versus Minimum Sliding Block Force, is approximately one half the theoretical value given in Table 4.10-1, assuming that all blades have equal spindle torque. The difference between the theoretical and actual transfer functions is due to friction in the pitch change mechanism and the inaccuracies in the calibration of the sliding block for negative loads.

The transfer function shown in Figure 4.10-9 of the Minimum Sliding Block Force Versus Minimum Blade Spindle Torque is larger than the theoretical value shown in Table 4.10-1. This is due to the difficulty encountered in calibrating the side of the sliding block which responds to negative spindle torques, as covered in the previous section.

Figure 4.10-8 shows the transfer function of Maximum Servo Oil Pressure Versus Minimum Blade Spindle Torque. The value of the theoretical transfer function is approximately twice the value of the measured transfer function given in Table 4.10-1. The factor of 2 is reasonable because the internal friction of the hub components reduces the pressure transmitted to the oil due to spindle torques. In addition to the internal friction limiting the load transmitted, the minimum spindle torque only occurs on one blade at a time and therefore the graph does not represent steady state conditions.

Figure 4.10-9 shows the transfer function of Mean Servo Oil Pressure Versus Mean Sliding Block Force. The theoretical transfer function compares well with the actual transfer function as listed in Table 4.10-1. This is reasonable because it represents the average load on all of the blades.

Figure 4.10-10 shows the transfer function of Mean Sliding Block Force Versus Mean Spindle Torque. The transfer function shown in Figure 4.10-10 is larger than the theoretical transfer function given in Table 4.10-1. This is due to the large scatter in the results. The scatter in the results is due to the combined effects of the inaccuracy of the sliding block calibration factor for negative sliding block loads, and the drifting of the sliding block signal mean. The mean sliding block signal drifted during the quarter bridge tests because the quarter bridge could not be temperature compensated.

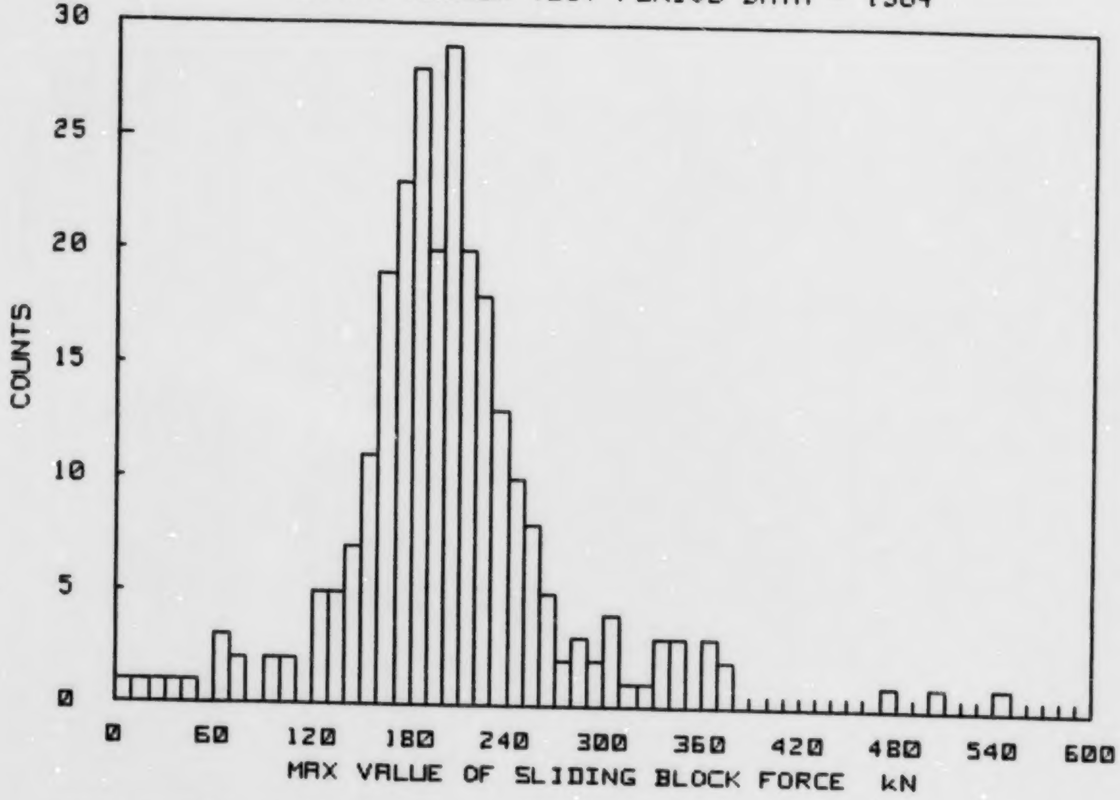
Figure 4.10-11 shows the transfer function of Mean Servo Oil Pressure Versus Mean Blade Spindle Torque. There is a large scatter in the data. This is why the value measured in Figure 4.10-11 does not match the theoretical value listed in Table 4.10-1. One possible source of scatter in the data is the fact that the pitch change mechanism operates in response to ice-propeller interactions, causing the system to be nonsteady state.

In order to determine the friction in the hub which reduces load on the sliding block, the characteristics of the sliding block loads during the tests, are studied. Figures 4.10.1-1 and 4.10.1-2 show the maximum excursions of the sliding block signal. There is less data available for the minimum sliding block loads, because the half bridge configuration of the sliding block was only good for 56 tests, while the quarter bridge configuration, which was only able to give positive sliding block loads, operated for 206 tests.

In order to estimate the reduction in the sliding block load due to friction, the tests with the three largest sliding block loads were studied. These are test numbers 54,166 and 178. Plots of the Sliding Block Force Versus Spindle Torque, during the three extreme events, are given in Figures 4.10.1-3 to 4.10.1-5. These figures show the same hysteresis evident during the static blade calibrations of the propeller blade on the Wurmlinger.

Assuming that the torque required to overcome friction is one half the width of the hysteresis loop

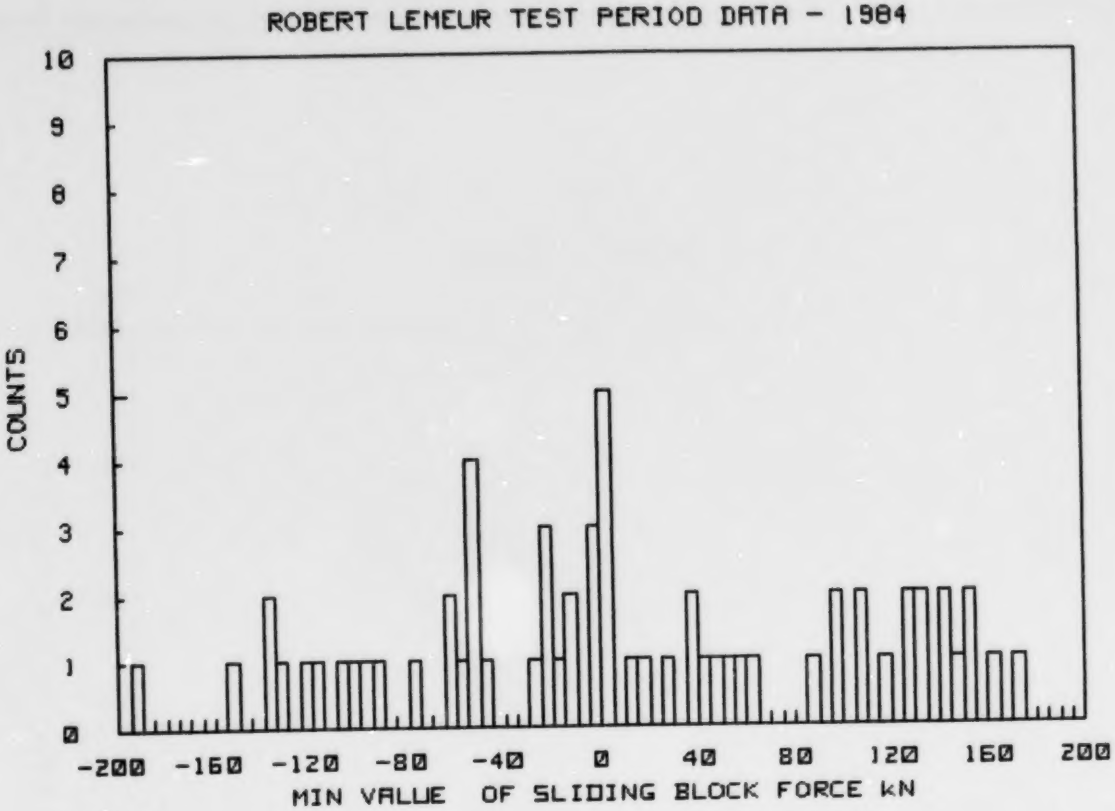
ROBERT LEMEUR TEST PERIOD DATA - 1984



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 262
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:204.29
AND ITS STANDARD DEVIATION IS:67.067

ALL DATA USED

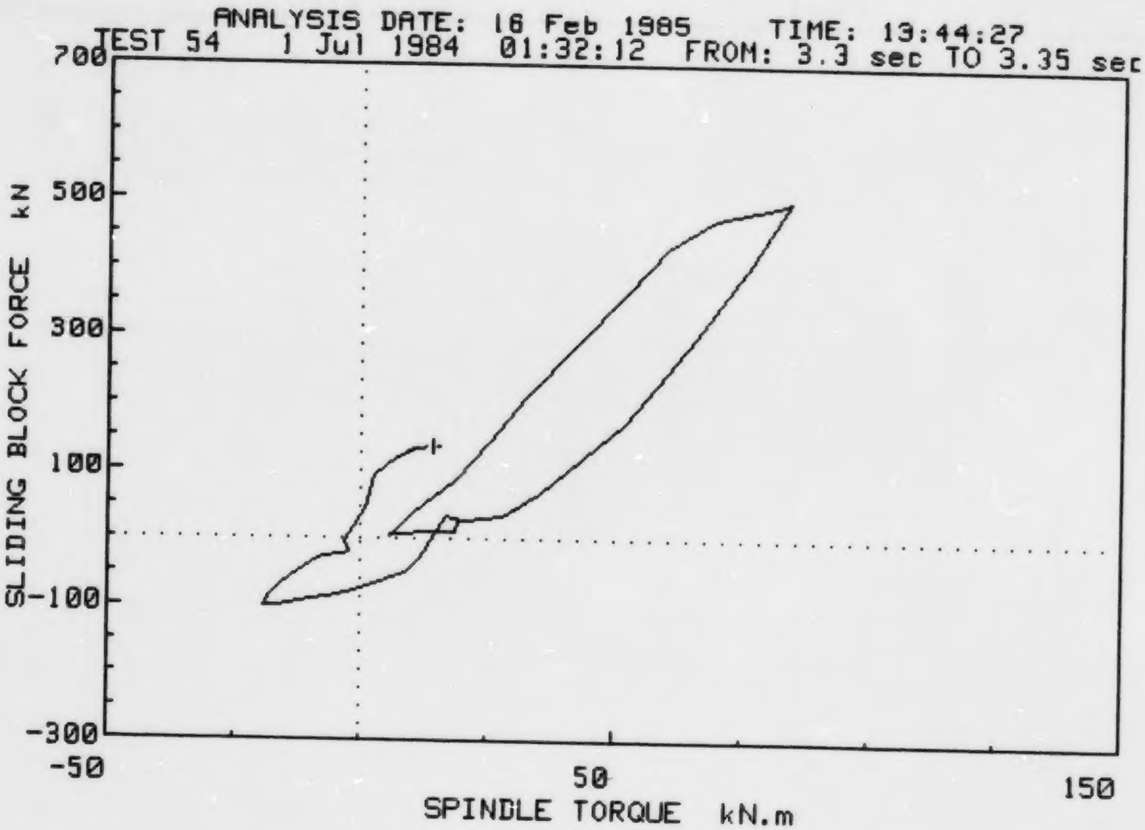
CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: MAXIMUM SLIDING BLOCK FORCE HISTOGRAM
		FIGURE No. 4.10.1-1



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 62
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:9.0527
AND ITS STANDARD DEVIATION IS:91.990

ALL DATA USED

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: MINIMUM SLIDING BLOCK FORCE HISTOGRAM FIGURE No. 4.10.1-2

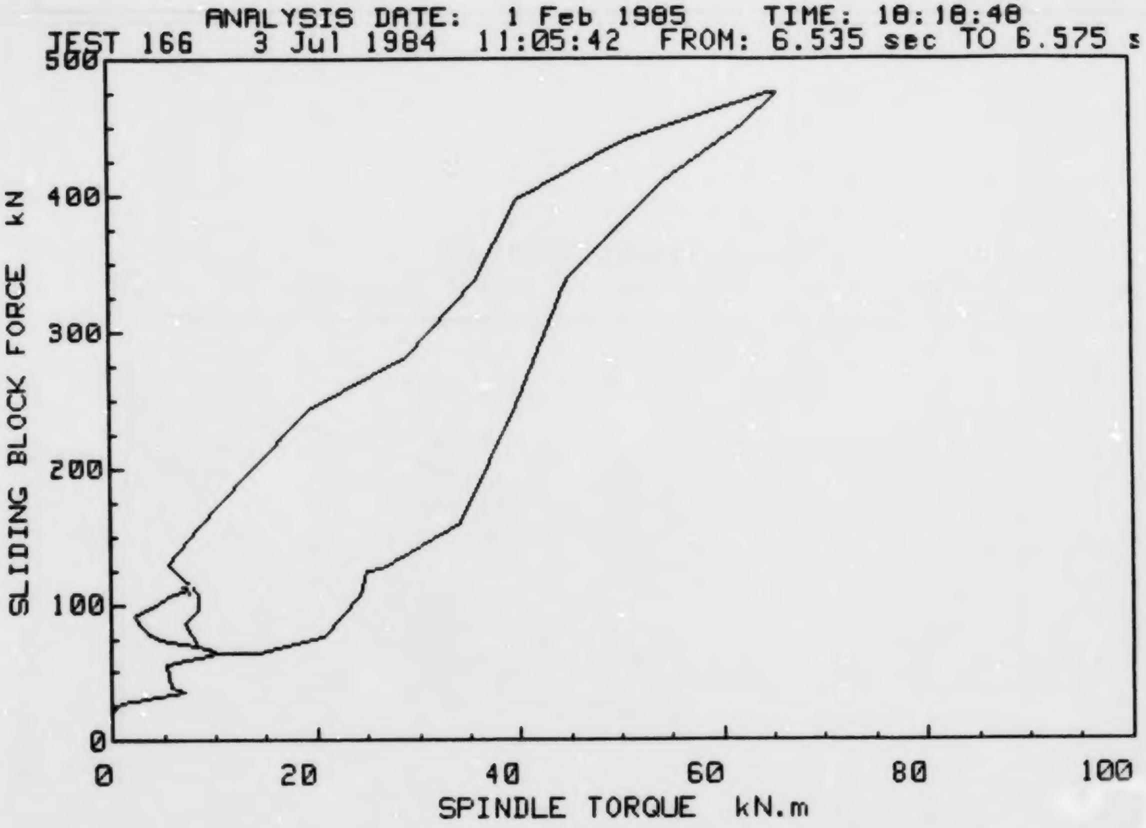


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: SLIDING BLOCK FORCE VERSUS SPINDLE TORQUE, DURING ICE- PROPELLER INTERACTION, EVENT No. 54

FIGURE No. 4.10.1-3

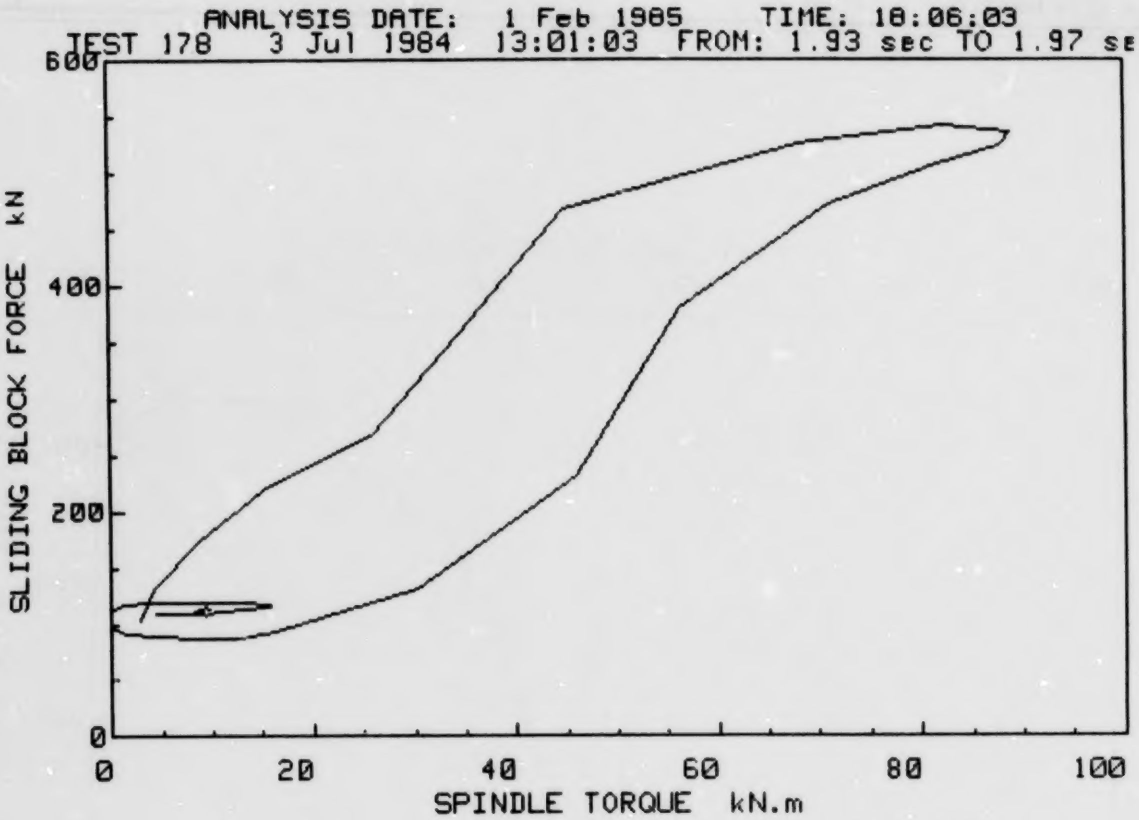


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: SLIDING BLOCK FORCE VERSUS SPINDLE TORQUE, DURING ICE- PROPELLER INTERACTION, EVENT No. 166

FIGURE No. 4.10.1-4



CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: SLIDING BLOCK FORCE VERSUS SPINDLE TORQUE, DURING ICE- PROPELLER INTERACTION, EVENT No. 178

FIGURE No. 4.10.1-5

yields the results presented in Table 4.10.1-1. These calculations show that during an event, approximately 90 percent of the spindle torque experienced by the blade may be transmitted as force to the sliding block.

In summary, the analysis of the sliding block, spindle torque and servo oil pressure signals shows that the maximum excursions of the blade spindle torque and sliding block loads cannot be measured accurately with the servo oil pressure sensor, due to friction in the pitch change mechanism, and that the friction in the blade carrier system limits the load on the sliding block to 90 percent of the value calculated assuming no friction.

4.11 Shaft Bearing Results

4.11.1 Introduction

The motivation for studying the movement of the shaft within the stern-tube bearing stemmed from Canmar's involvement in a number of bearing misfortunes. Canmar engineers discovered that many arctic shipping operators had experienced other modes of failure of their bearings, but details were not public knowledge. It was realised that bearing design for arctic operation was in a state of flux, and the situation was further compounded by the total lack of design guidance in the current Arctic Shipping Pollution Prevention Regulations, (ASPPR). Reliance was apparently being placed on the approaches taken by the various Classification Societies to the question of bearing design; approaches reflecting long-established practices which have been found adequate for open-water applications.

As the ultimate goal for these research projects is to influence the adoption of new ASPP Regulations, an understanding of bearing performance requirements would be an appropriate first step. Accordingly two inductive proximity probes were installed at right angles to each other across a plane just forward of the forward face of the aft stern-tube bearing, and a similar pair was installed aft of the aft face. Details of the probes, and of their installation, can be found in the Milestone 1 report, Subsection 2.3.

The intentions of the probe installations were to measure both horizontal and vertical movements of the shaft relative to the bearing and, by the inclusion of both forward and aft sensors, to determine the extent of misalignment of the shaft within the bearing. These

EVENT NUMBER	FRICTIONAL SPINDLE TORQUE kNm	PEAK MEASURED SPINDLE TORQUE kNm	FRICTIONAL PORTION OF PEAK TORQUE %
54	10.7	82.0	13
166	5.5	65.84	8
178	10.0	88.3	11

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TITLE: FRICTIONAL SPINDLE TORQUE FOR THE THREE LARGEST SLIDING BLOCK FORCES

TABLE No. 4.10.1-1

readings would be correlated with the output of the other transducers in the drivetrain to increase the level of understanding of the workings of a bearing operating in ice.

Unlike other specific topics of measurement within the project, i.e. blade, shaft, or CPP mechanism, a mathematical model of a bearing was not proposed. This deviation was governed by the appreciation that such a model would require a substantial effort and should be performed by specialists unavailable within Canmar's range of expertise.

4.11.2 Data

The proximity probes did not live up to expectations. One, designated the Forward Starboard probe, failed immediately following installation and therefore no readings were taken from this source. Two others ceased to function shortly after the tests began. A listing of the tests and active probes is provided below:

Probe Location	Channel Number	Functional in Test Numbers
Aft Port	11	8 - 12 inclusive
Aft Top	12	8 - end of program
Forward Port	13	8 - 12 inclusive
Forward Starboard	14	did not function

The channel numbers refer to the "ANALYZE4-1" listing provided in Table 4.1-1.

4.11.3 Analysis

The analysis of the data focuses primarily on Tests 8 - 12 with Test 8 warranting the most attention. These tests were taken during the setting-up phase of the instrumentation. It was fortunate that Test 8 happened to record the fifth highest blade force, which made it worthy of in-depth analysis.

Figures 4.11.3-1 to 4.11.3-5 show the Lissajous figures for Tests 8 - 12 inclusive, depicting the motion of the shaft at the aft face of the bearing. These traces were recorded over the full time interval of each event, i.e., approximately seven seconds. Figure 4.11.3-6 traces the maximum excursions resulting from the five tests.

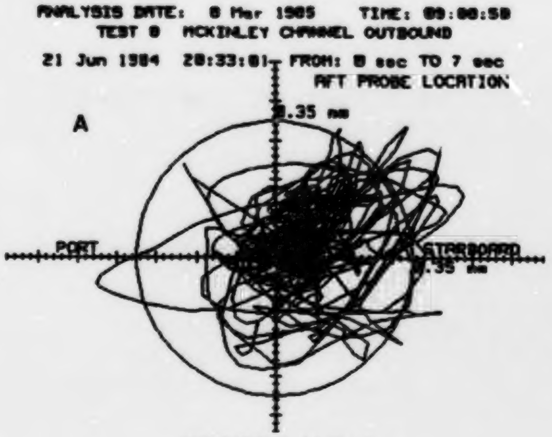


FIGURE 4.11.3 - 1

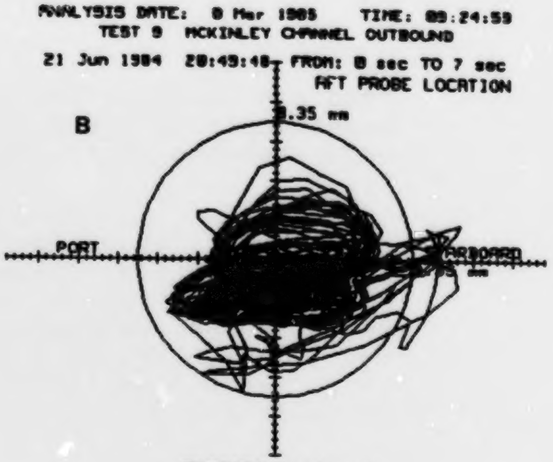


FIGURE 4.11.3 - 2

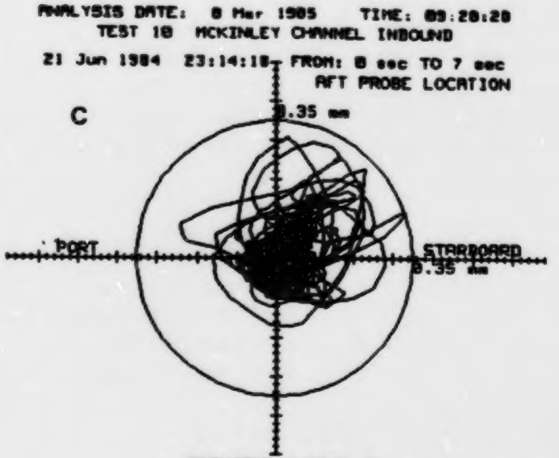


FIGURE 4.11.3 - 3

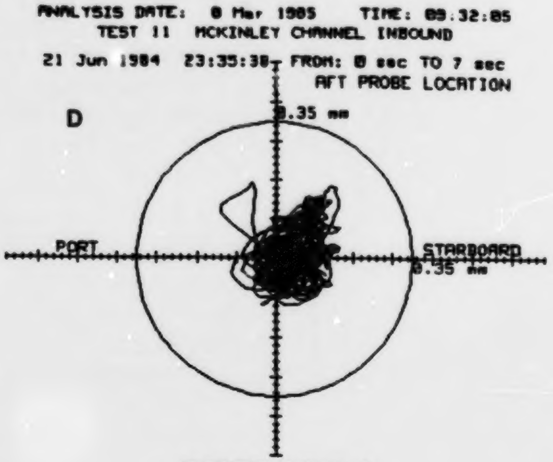


FIGURE 4.11.3 - 4

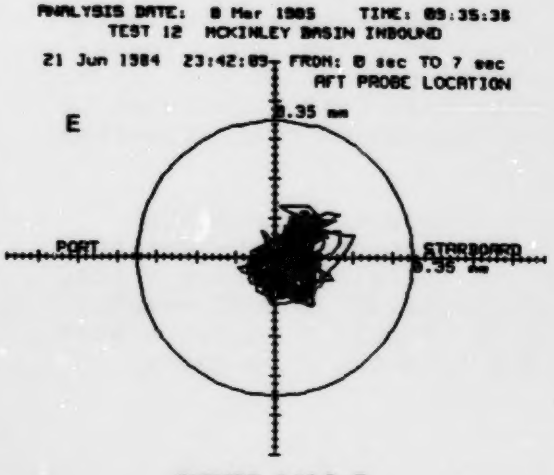


FIGURE 4.11.3 - 5

EXTREME EXCURSIONS TESTS 8 TO 12

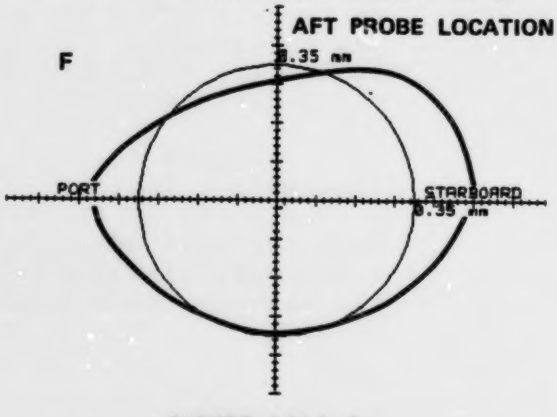


FIGURE 4.11.3 - 6

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: LISSAJOUS FIGURES FOR TEST 8 TO 12

FIGURE No. 4.11.3 - 1 TO 6

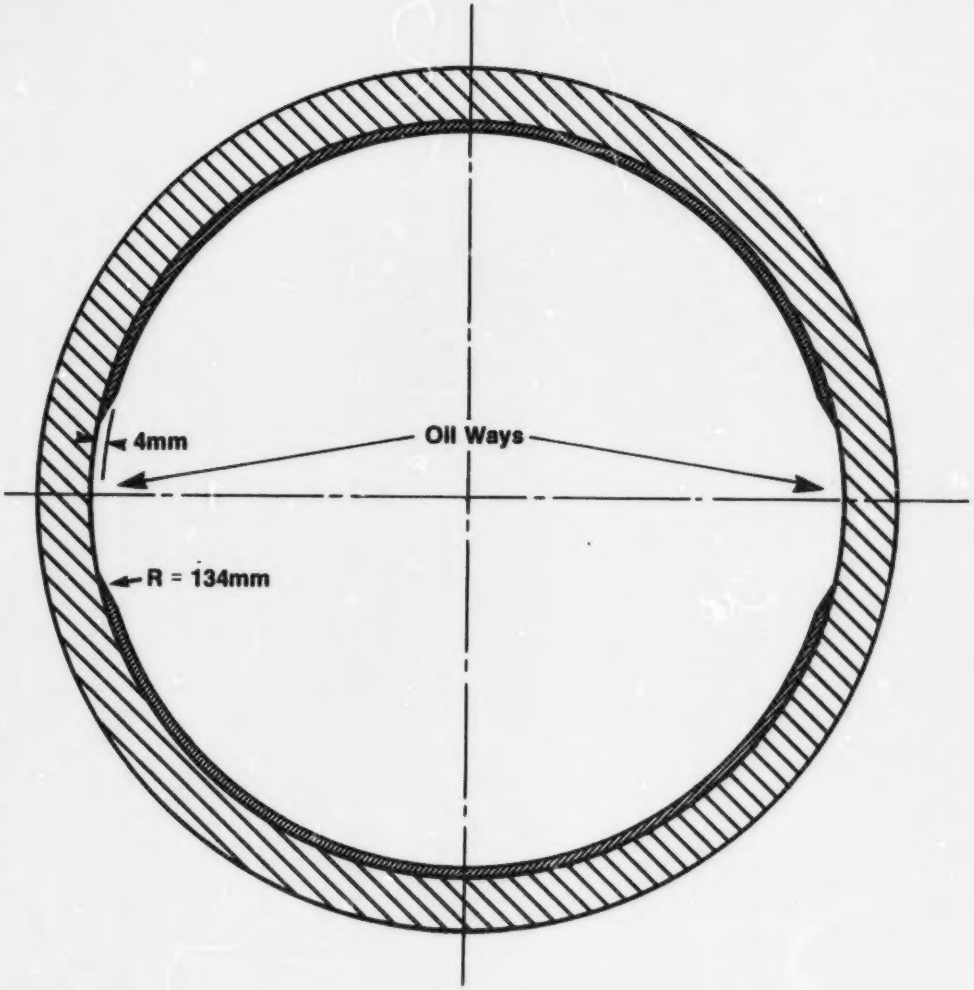
There is uncertainty about the interpretation of Figures 4.11.3-1 to 4.11.3-6, both in respect to location within the bearing and to the amplitude of the apparent shaft movements.

The intersection of the horizontal and vertical graduated scales is believed, from the static calibration records available, to represent the centre of the shaft, at rest, with the ship afloat. The circle in each figure has been drawn to a scale equivalent to a 0.35 mm radius, the sizing chosen to accord with the known diametrial running clearance of the bearing of 0.7 mm.

Two difficulties arise from these interpretations. The first difficulty is that due to the overhang of the heavy icebreaking propeller, even while submerged in water, the shaft was almost certainly resting on the lower lip of the bearing of its aft edge when it was stationary. Under these circumstances, the running clearance circle should be located above and just touching the horizontal graduation. The subsequent motion of the shaft would be expected to be within the prescribed circle of 0.7 mm diameter.

The second difficulty is the extent of the shaft movement, particularly Figures 4.11.3-1 and 4.11.3-2, which has been exemplified in Figure 4.11.3-6. The horizontal excursion of these traces, (and the vertical excursions if the location of the at-rest shaft centre line is as shown), suggests local compliance of the bearing. It may be possible to explain the horizontal motion by the existence of the oilways which have been machined into the bearing profile. Figure 4.11.3-7 provides details of the whitemetal bearing.

While the scaling factor and the zero offset might cause some confusion, it is believed that the calibration constant was consistent for all four transducers. Therefore, the traces can be interpreted as representing true motion albeit to some unknown scale. Within this contention, it is readily apparent that the horizontal motion of the shaft dominates the vertical motion. This finding may be ascribed to either a predominantly horizontal directional impulse from blade/ice interaction, or to a relatively lower resistance of the shaft to horizontal motion than to vertical motion. The latter explanation is considered more likely, but the subject needs closer study.


4mm
Oil Ways
R = 134mm

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DRILLING
LIMITED

MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE: WHITE METAL
BEARING DETAILS

FIGURE No. 4.11.3 - 7

Figure 4.11.3-8 examines Test 8 in greater detail. Both of the aft probe traces are shown over the full time span of approximately seven seconds. The blade force and shaft torque signals are also included. The periodicity of shaft rotation is recognizable in all the traces, except shaft torque, and is slightly under 0.3 seconds. The periodic pattern becomes obscured, at this time magnification, in the two probe traces during periods of ice interaction. The specific areas of interest in Test 8 occur at time "t" between 1 and 2 seconds and between 4 and 5 seconds. These time periods are examined in greater detail below.

Figures 4.11.3-9 and 4.11.3-10 contain the same four traces over the one second intervals of specific interest. Figure 4.11.3-11 provides the corresponding Lissajous figures.

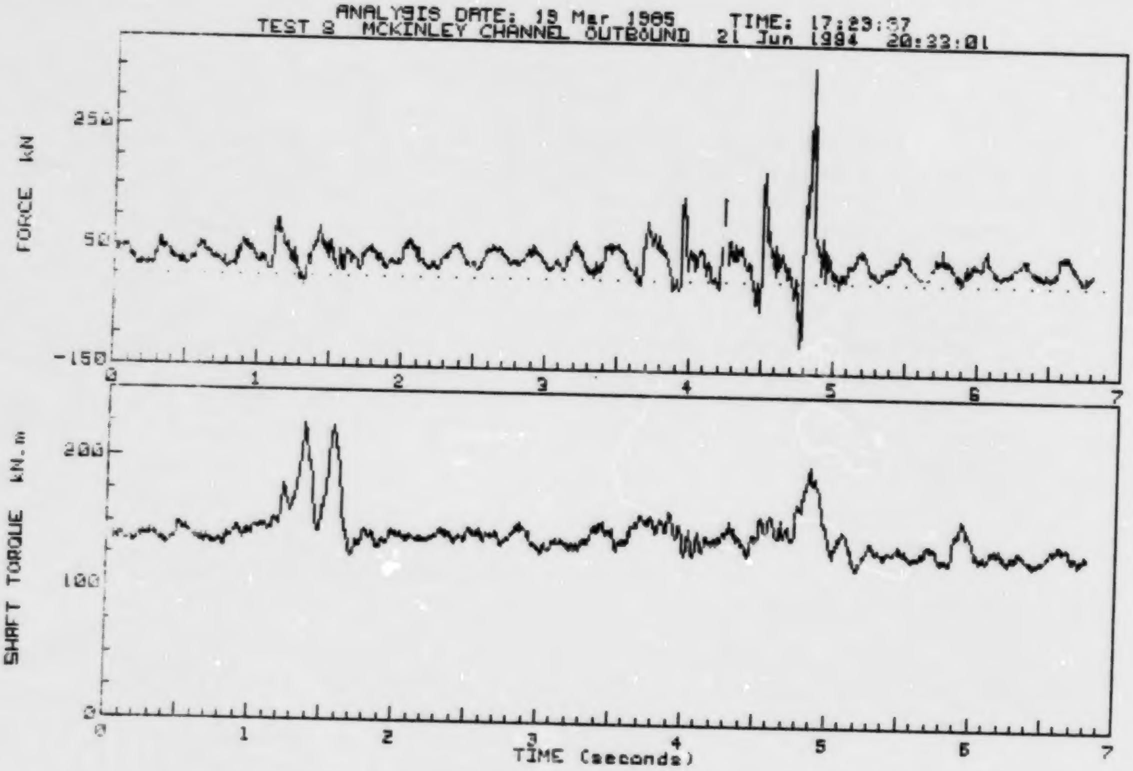
The periodicity of the shaft rotation is highlighted particularly well in the Blade Force trace of Figure 4.11.3-10; the clarity being due to the fact that only one blade in four was instrumented. The shaft torque trace exhibits no such response, but does indicate a gradual increase in torque as the milling of the ice-block progressed. A significant rise can be seen near the end of the trace, in response to the blade force peak immediately preceding. A similar "kick" in the shaft torque trace following ice-block activity is found in Figure 4.11.3-9, although in this case, a double hump is observed with a period of approximately 0.2 seconds. The investigation of this occurrence is outside the scope of the bearing analysis.

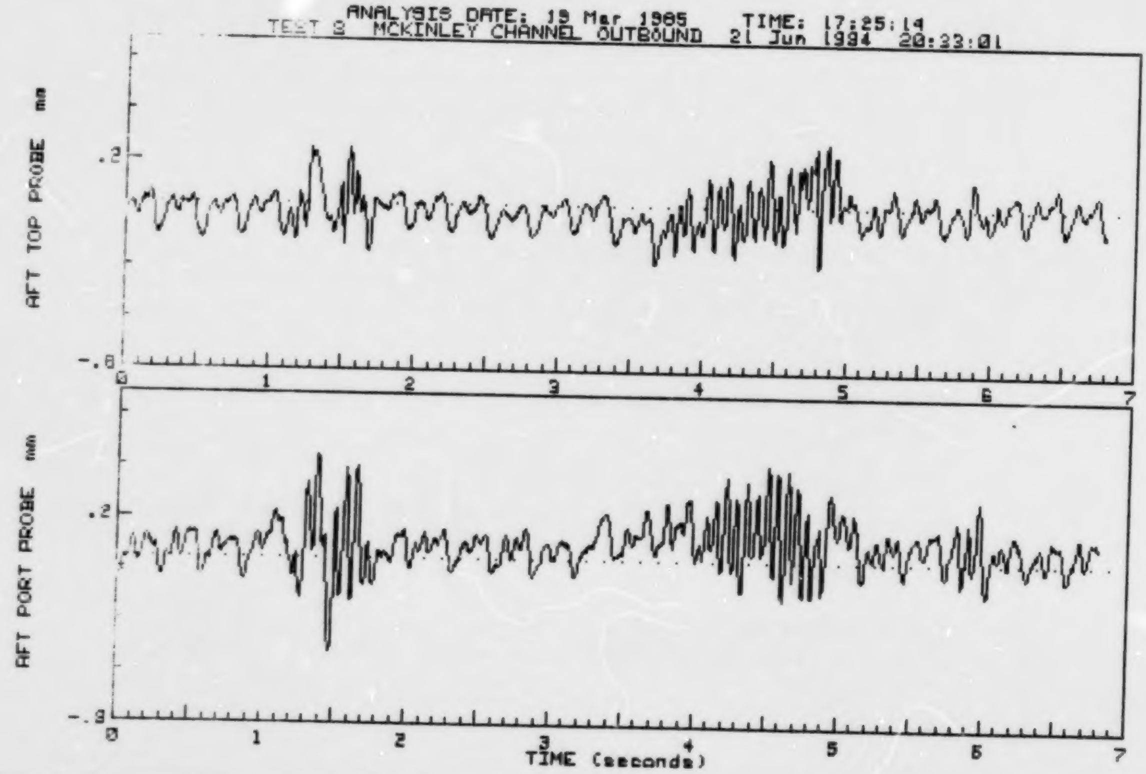
Of immediate importance are the periodic fluctuations in the probe traces. These are strongly correlated to the blade-passing frequency showing four to each shaft rotation although they have been influenced by other harmonics.

The most important aspects about the probe traces are:

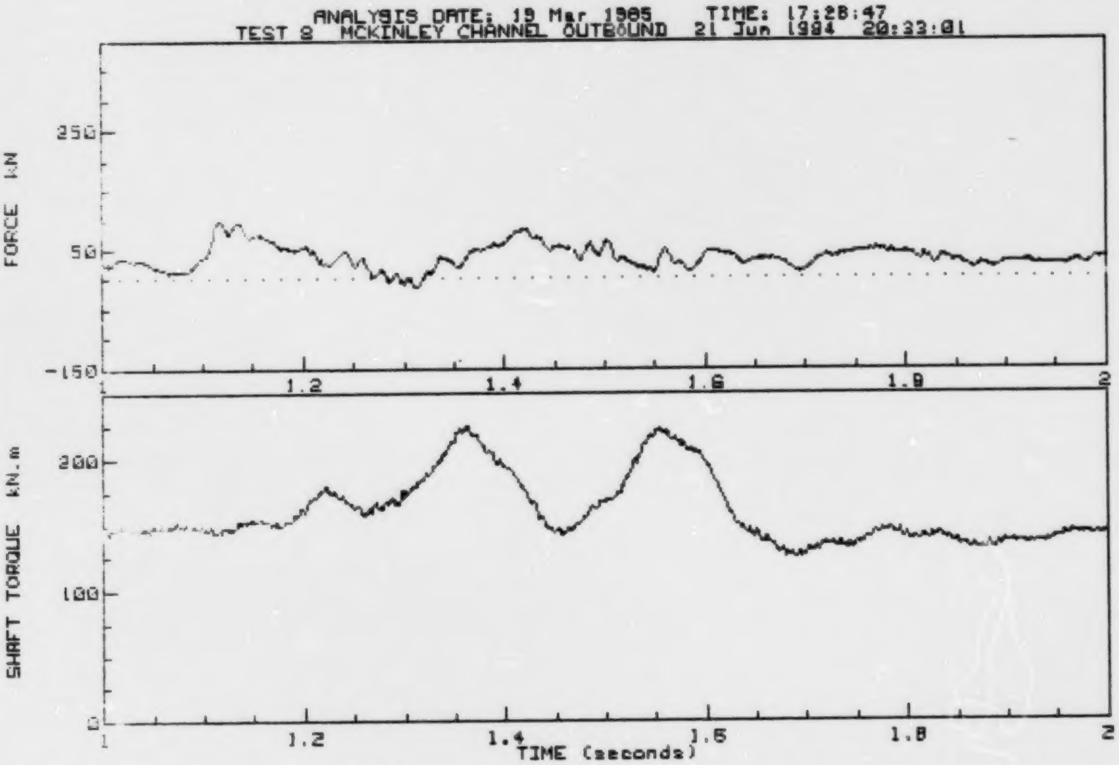
- The peak-to-valley excursions
- The shape of the trace at the extreme excursions
- The phase relationship between the port and top traces

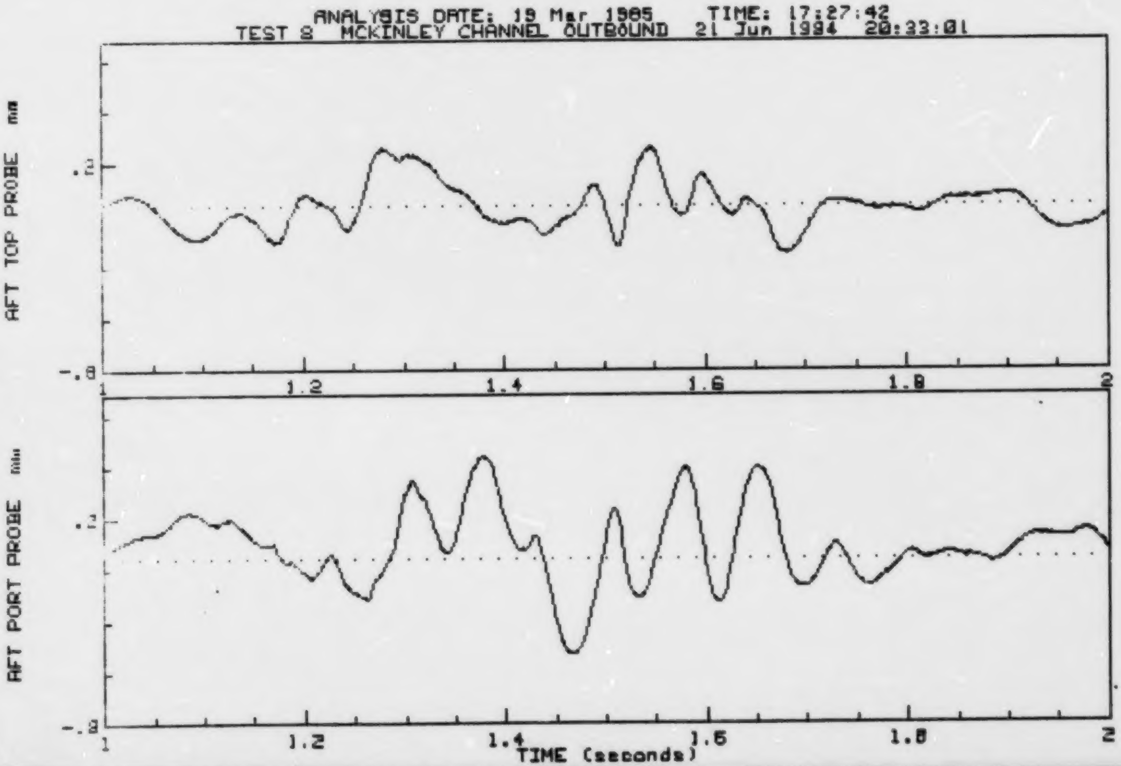
The maximum range in the port trace of Figure 4.11.3-9 is from approximately +0.5 mm to -0.5 mm i.e.



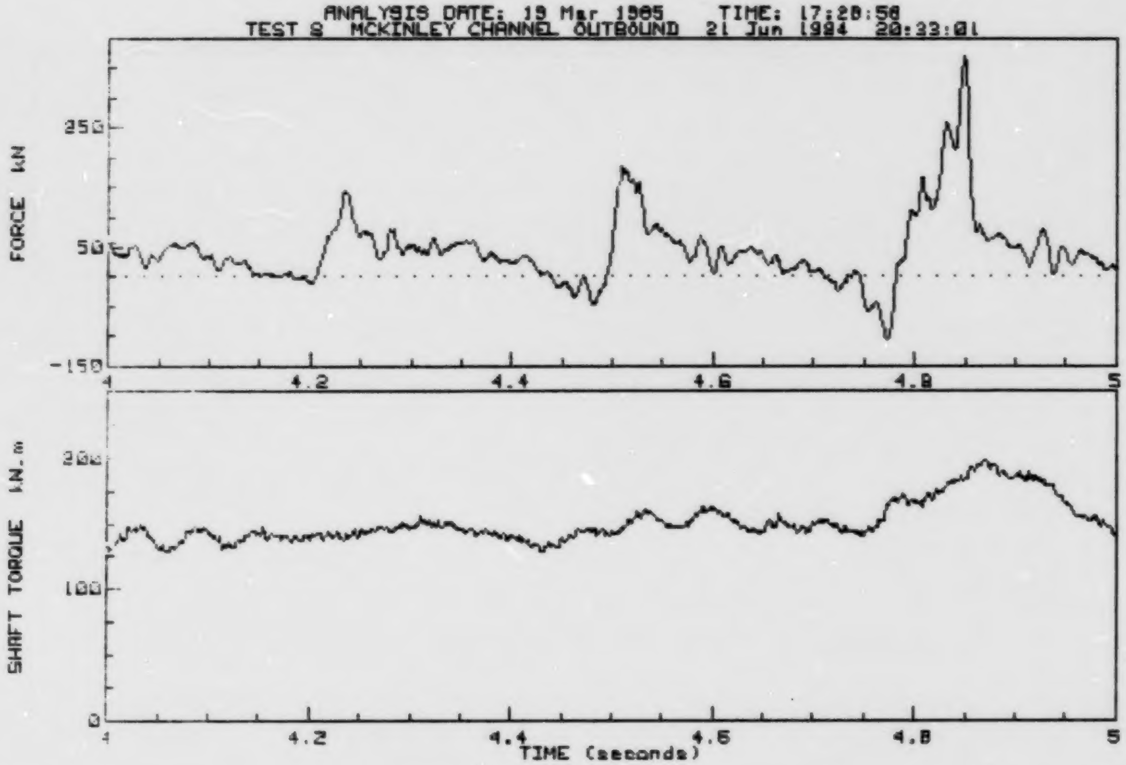


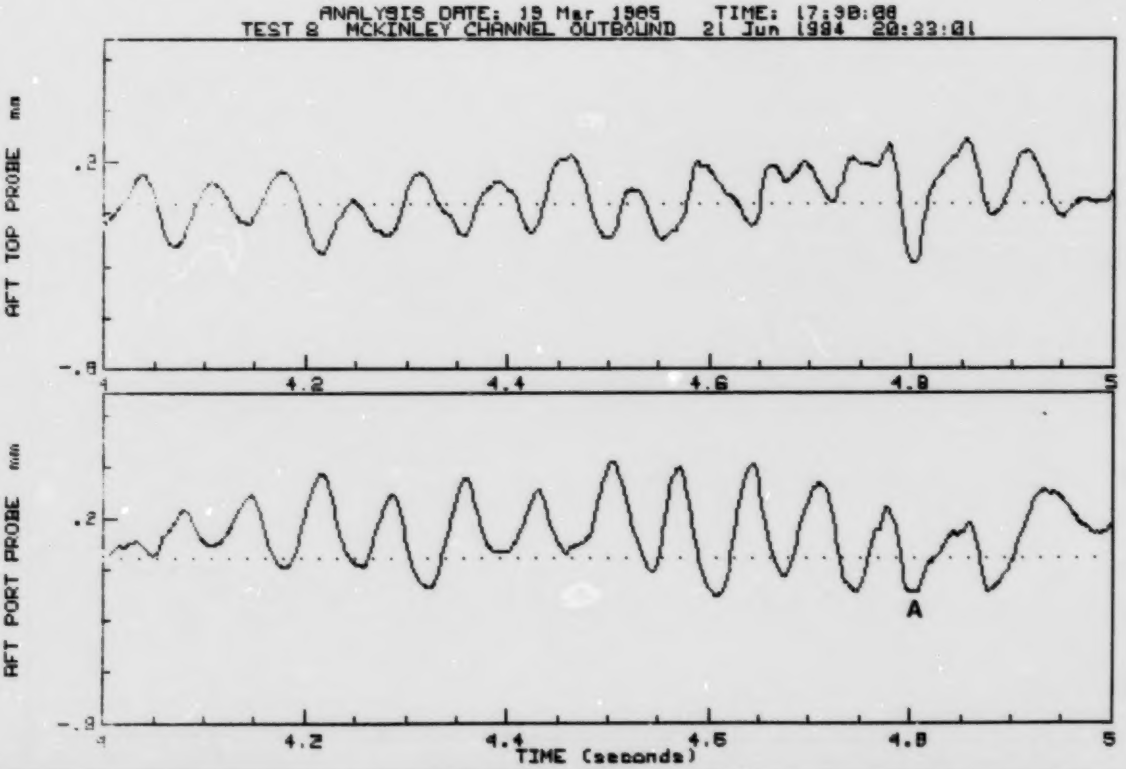
CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** TEST 8 BEARING ANALYSIS TIME 0 - 7 SECONDS
		FIGURE No. 4.11.3 - 8





CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: TEST 8 BEARING ANALYSIS TIME 1 - 2 SECONDS**
		FIGURE No. 4.11.3 - 9



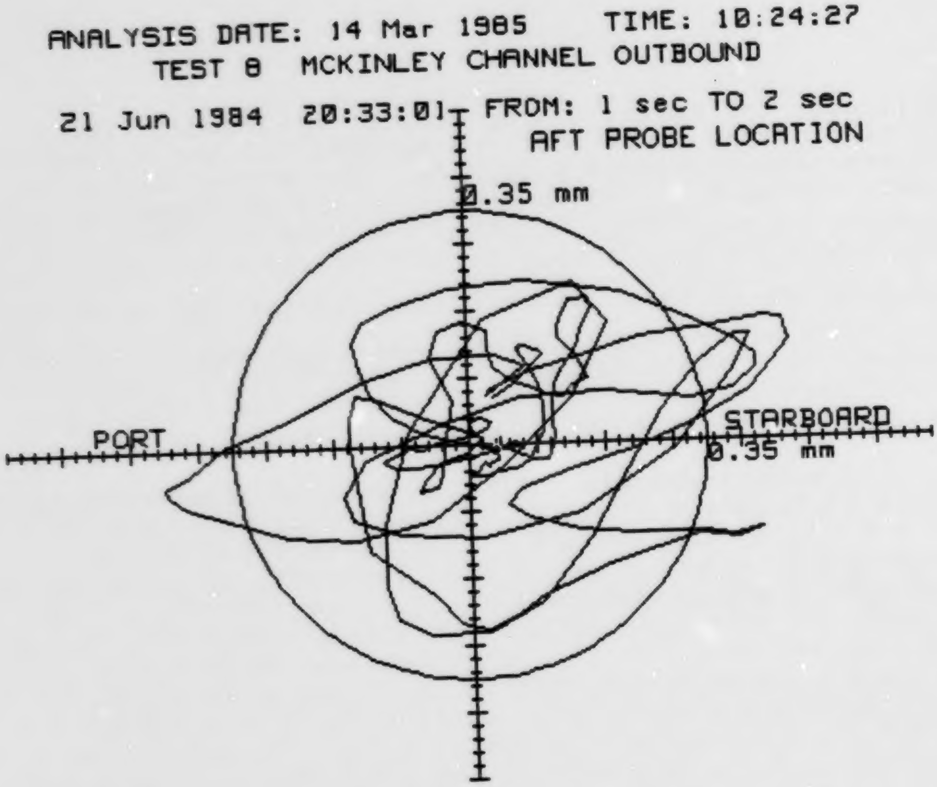


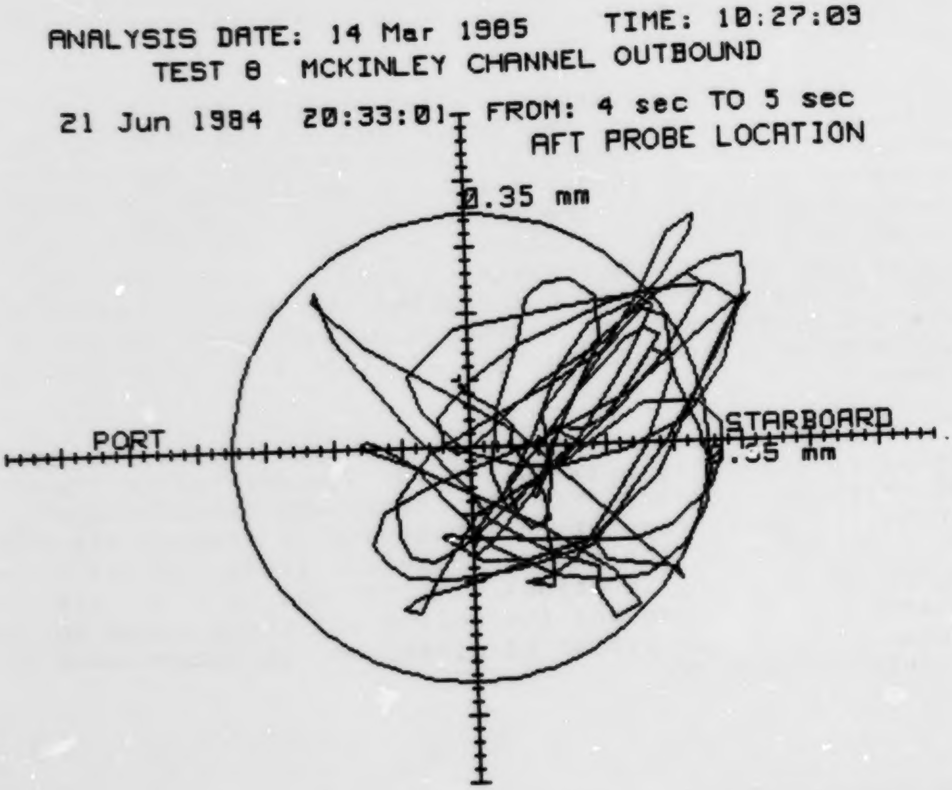
CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **TEST 8**
BEARING ANALYSIS
TIME 4 - 5 SECONDS

FIGURE No. 4.11.3 - 10





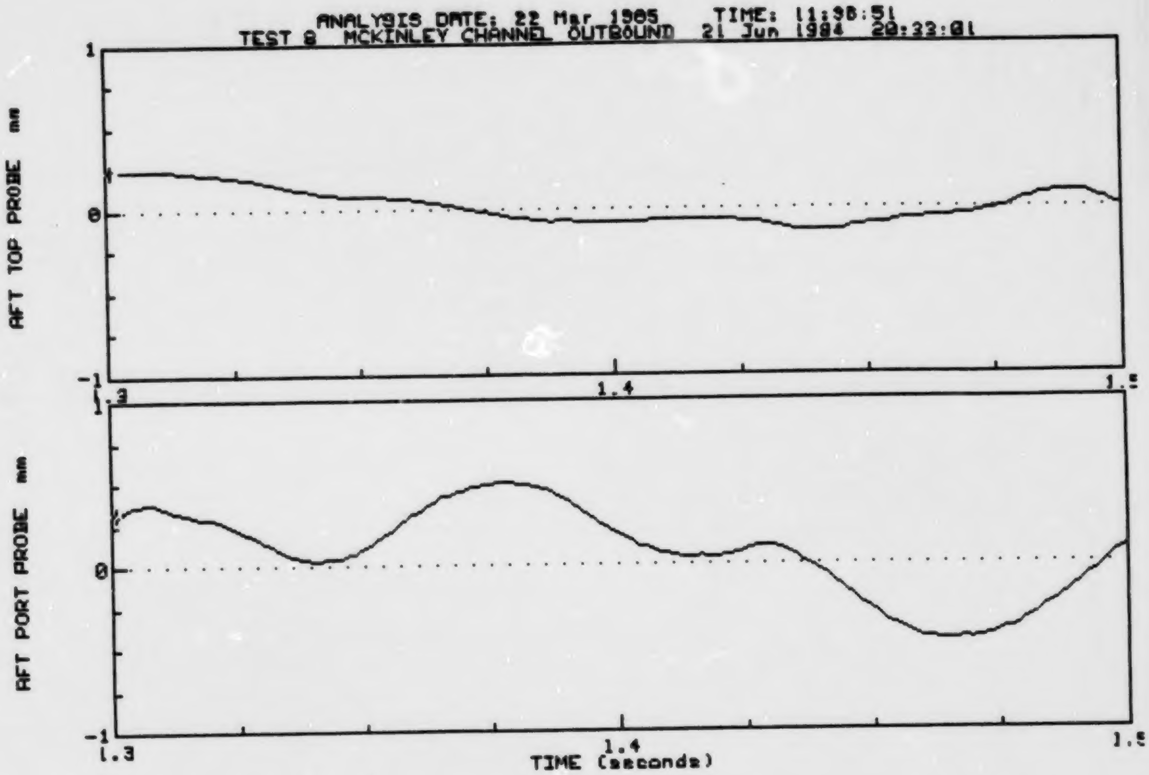
CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: TEST 8 LISSAJOUS FIGURES TIME 1 - 2 SEC. AND 4 - 5 SECONDS**
		FIGURE No. 4.11.3 - 11

well over the stated 0.7 mm running clearance. This portion of the trace, for "t" between 1.3 and 1.5 seconds is expanded in Figure 4.11.3-12. The actual motion of the shaft can be followed in the accompanying Lissajous figure, but it should be noted that the top probe trace has been reversed in sign in this figure. Another point to remember is that the top probe was located at 15° from the vertical to port, and the port probe was 15° below the horizontal. These offsets are reproduced on the probe traces but have been eliminated in the Lissajous figure which portrays true vertical and horizontal motion.

A second example with the expanded time scale is given in Figure 4.11.3-13. These traces represent "t" from 4.62 to 4.82 seconds. This example was chosen because it included one of the flat spots at a valley in the port trace of Figure 4.11.3-10, as depicted by the letter "A" on both figures. This flat might indicate the contact and dwell of the shaft against the bearing surface. Under magnification, a sister flat may be observed on the top trace, designated by the letter "B". These flats coincide with point "C" on the Lissajous figure, lending credence to the possibility of an impact against the bearing surface at that location. Point "C" is one of the extreme excursion points forming the outline in Figure 4.11.3-6.

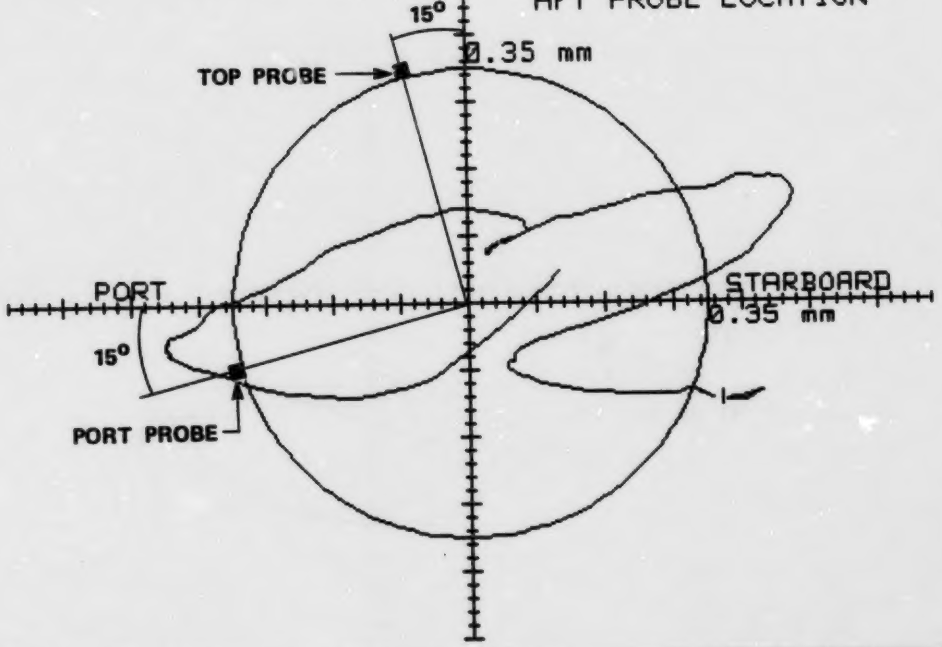
Point "C" is assumed to represent a collision between the shaft and the upper half of the bearing on the strength of the evidence presented in Figure 4.11.3-13. However, it would be desirable to explain why the impact registered a flat on the probe traces rather than a cusp. It would also be advantageous if points "D" and "E" on the Lissajous figure (equivalent to locations "F", "G" and "H", "I" respectively on the probe traces) also exhibited similar patterns. The digital limitations of the probe trace drawing medium prevents positive identification of flats.

Another point of interest in Figure 4.11.3-13 is the phase relationship between the top and port probe traces. At locations "G" and "F", the traces are out-of-phase as shown. This configuration represents an upper-starboard to lower-port motion on the Lissajous figure, as evidenced by point "D". At locations "I", "H" and "B", "A" the traces are in-phase and the motion has swung round to the upper-port, lower-starboard direction, as illustrated by points "C" and "E".



ANALYSIS DATE: 22 Mar 1985 TIME: 11:36:51
TEST 8 MCKINLEY CHANNEL OUTBOUND 21 Jun 1984 20:33:01

ANALYSIS DATE: 22 Mar 1985 TIME: 11:37:28
TEST 8 MCKINLEY CHANNEL OUTBOUND
21 Jun 1984 20:33:01 FROM: 1.3 sec TO 1.5 sec
AFT PROBE LOCATION



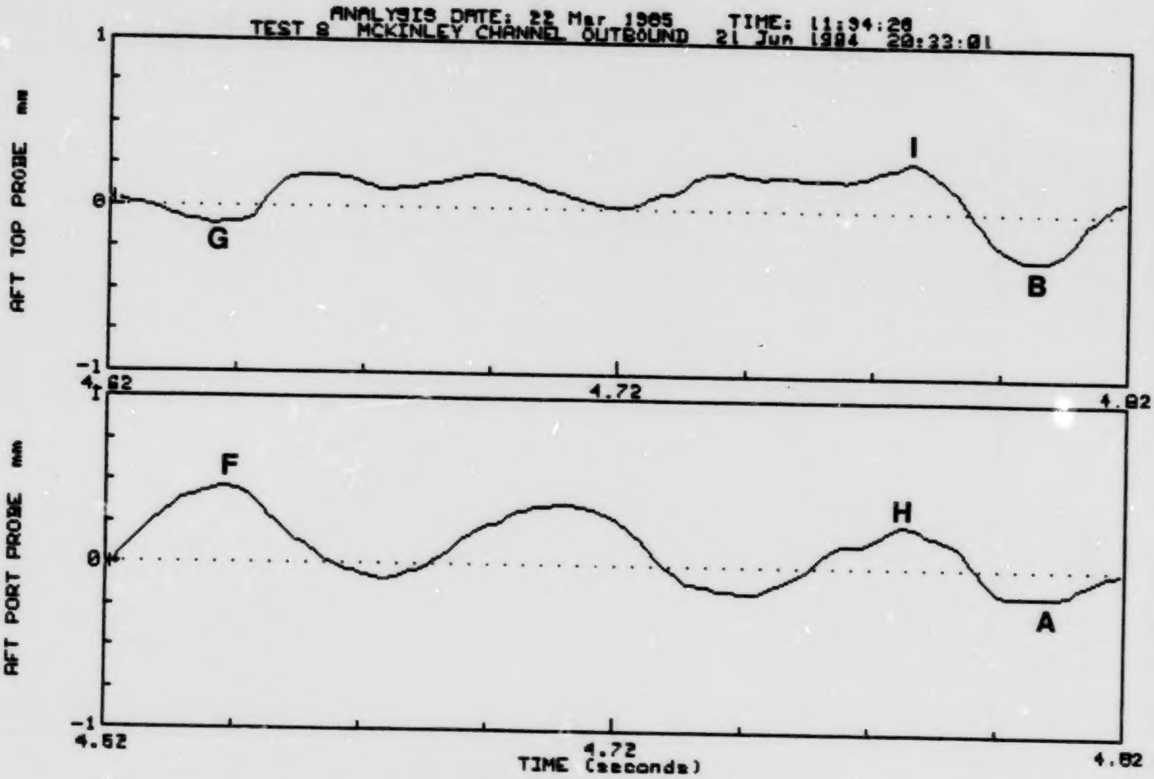
CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

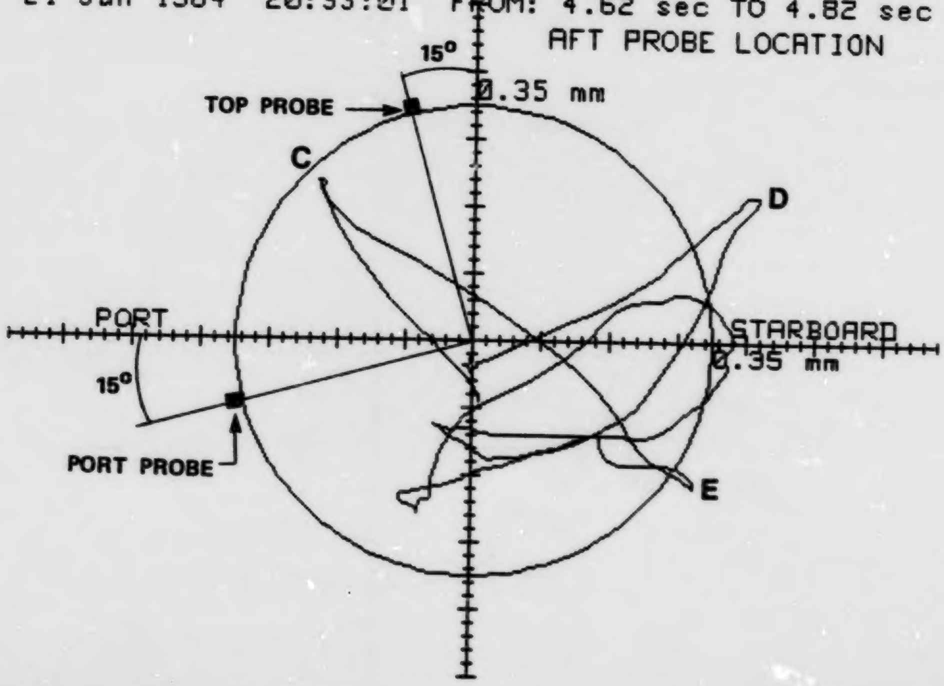
TITLE: TEST 8 BEARING ANALYSIS TIME 1.3 TO 1.5 SECONDS

FIGURE No. 4.11.3 - 12

ANALYSIS DATE: 22 Mar 1985 TIME: 11:34:28
TEST 8 MCKINLEY CHANNEL OUTBOUND 21 Jun 1984 20:33:01



ANALYSIS DATE: 22 Mar 1985 TIME: 11:35:19
TEST 8 MCKINLEY CHANNEL OUTBOUND
21 Jun 1984 20:33:01 FROM: 4.62 sec TO 4.82 sec
AFT PROBE LOCATION



CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: TEST 8
BEARING ANALYSIS
TIME 4.62 - 4.82 SECONDS

FIGURE No. 4.11.3 - 13

4.11.4 Conclusions

- There is a greater tendency for horizontal motion than vertical motion of the shaft in the aft stern-tube bearing.
- The motion is erratic and is forced at the blade passing frequency.
- The shaft may contact any area of the bearing surface, whether on the lower or upper surfaces, as a consequence of the vibratory impulses imposed during ice/propeller interaction.
- The performance of the bearing, even at the essentially constant RPM of this test project, is outside the predictive capability of the standard hydrodynamic bearing theory.

4.11.5 Recommendations

- The test results require further study to determine.

  i. Scaling factor and zero offsets for the traces
  ii. Misalignment data
  iii. Acceleration forces created by radial displacement of the shaft

- A bearing model should be developed capable of substantiating as far as possible, the findings of these field results.

5. ANALYSIS OF LONG TERM SHAFT STATISTICS

5.1 Introduction

The five-day field test program from June 30 to July 4, 1984, produced an intensive amount of data from the transducers installed throughout the starboard propulsion train. During that time period, the MV Robert LeMeur was engaged in breaking through decaying ice as the spring break-up progressed. It was recognized that the collection of a full season of data would be a valuable addition to the knowledge gained about the effect of ice-interaction on ships in general, and on that ship in particular.

Because of the limited reliability of the many transducers, and the logistics of continuing a full-scale data collecting operation, it was neither practical nor desirable to attempt to maintain the same degree of information gathering for the remainder of the season. Therefore, a compromise was reached. The proven reliability of the strain gauges permanently mounted on the Intermediate Shaft offered the possibility of obtaining a full season of data based on the thrust and torque signals collected from this source. Accordingly, an automated data collection system was installed, which operated from July 4 until the end of the season on October 29, 1984.

Two types of recording equipment were installed; the first accumulated statistical data from the torque and thrust signals using "DATAMYTE" modules; the second recorded sample readings of torque, thrust and ship speed signals on a "Terra Technology DCS-302" digital recorder. Further details on these two systems are given in Subsections 5.3 and 5.4.

A third source of information was the ship's log. This document was reviewed during the analysis period following the accumulation of the season's data. The objective was to correlate the shaft information with the description of operational procedures onboard the ship. From this reference, an estimation of the time the vessel was stationary, the net time travelling through open water, and the net time operating in ice, could be deduced.

From all this information, it was possible to paint a picture of a season's propulsion loads and ice conditions for a supply and ice-defence vessel operating in the Beaufort Sea. In particular, the time periods, or activities, stressing the propulsion system could be identified, and some long term statistics of propulsion train load levels could be compiled with regard to both frequency and severity.

5.2 Shaft Data Collection System

In order to resolve the details of a collision between an individual ice-block and a propeller blade, experience has shown that the detection system should be capable of linear resolution over a frequency range from steady state to 100 Hz. The electrical output from the system must also be specified with regard to the ease of subsequent data processing and analysis. These criteria were met with the same equipment used for the five day test.

Figure 1.2-1 identifies the location of the torque and thrust transducers permanently installed onboard the MV Robert LeMeur, ie. just aft of the engine room bulkhead. This installation uses a conventional strain gauge torque bridge compensated for shaft bending, and a "Hylarides" type thrust bridge also compensated for shaft bending as well as cancellation of the torque influence due to thrust gauge misalignment. Strain gauges have not been installed to monitor shaft bending.

The thrust and torque transducers were located aft of the gear box and rubber coupling, in order that the mechanical transfer functions of these devices would not influence the load signals emanating from the propeller blades. It is also believed that the mechanical losses associated with the various shaft seals and bearings aft of the strain gauges would have an insignificant influence (< 1%) on the operating torque, so that the torque transients at the detection location would closely follow the torque transients generated at the propeller.

The remainder of the instrumentation operated as follows: An on-shaft amplifying and transmitter unit converted the strain signals to frequency-modulated carrier signals which were capacitively coupled to a pickup adjacent to the rotating shaft. A receiver unit in turn converted the signals back to analogue voltages directly proportional to instantaneous shaft torque and thrust. The system is a British Hovercraft Corporation type BR 101 FM (Frequency Modulated) telemetry system.

After installation, the linearity and gain of the complete strain system was measured by performing shunt calibration tests of the strain gauge bridge. This data, in conjunction with the known geometrical and elastic properties of the shafting and known "gauge factors" of the strain gauges were used in order that the output voltage of the telemetry system could be expressed in terms of torque units. The linearity of the system was found to be better than ± 1 percent of full scale; full scale torque being approximately 350 kN.m., and full scale thrust being approximately ± 1,550 kN..

The 3 dB bandwidth of the system is 500 Hz.

5.3 The Datamyte Recording System

Two forms of statistical data were collected by the Datamytes. These were called "Real Time Rainflow" and "Time at Level". Initially, four Datamyte recorders were used; one each to handle Real Time Rainflow for the thrust and torque signals, and the other two to handle Time at Level from the same two signals.

The Datamyte process for Real Time Rainflow reacts to peaks and troughs in the incoming signal. Half of a cycle is counted when the slope of the signal changes sign, and the change in amplitude of the signal is greater than the "hysteresis" setting. Hysteresis is the term used to set the extent of offset of the incoming signal which is required before a change in direction is recognized. The higher the hysteresis setting, the larger the change must be before a half-cycle count will be accepted.

The half-cycles are converted to full cycles by the addition of a second half-cycle measured at some later time from the incoming signal.

The cycles of shaft strain, which depict thrust or torque in the present example, are sorted according to their "range" and "mean" values. Each of the Datamyte modules collects and outputs information in a maximum of 32 bins. The 32 bins cover the full range of expected signal levels, from the maximum negative value to the maximum positive value. The range of the incoming signal refers to the number of bins the signal passes through in each half-cycle counted. The mean of the signal refers to the bin level which marks the average of the peak and trough of that particular half-cycle.

It was found that the variation in the thrust signal resulted in an overflow in the memory of the Real Time Rainflow Datamyte. Rather than increase the hysteresis setting of the original thrust Real Time Rainflow module, an additional Real Time Rainflow Datamyte was placed in parallel with a hysteresis setting one step higher.

The Datamytes were interrogated four times during the 1984 operating season, resulting in four periods of similar length. Apart from the difficulties with the thrust Real Time Rainflow modules, the remainder of the Datamytes recorded successfully for the duration of the season.

The memory of the Real Time Rainflow Datamytes were interrogated at the end of each test period, using a Texas Instruments Silent 700 data terminal. This device produced a hard copy listing of:

- Program module number
- Test name
- Hysteresis setting
- Number of shutdowns
- Number of range overflows
- Elapsed time
- Statistical data

The other Datamyte program whose full title is "Time at Level Plus Level Crossings", performs two separate functions. The first function scans the input signal at a fixed frequency indexing the bin counter which corresponds to the current amplitude of the signal. The second function records, on a different set of bin counters, each time the input signal enters within the limits of a bin. A hysteresis setting is used to prevent a high frequency, low amplitude signal near the limits of one of the bins from causing excessive level crossing counts.

The raw data from the Datamyte modules was analysed using a HP 9845 computer. A software program, called "HIST13", was specifically written to plot a histogram from the Real Time Rainflow information. Another software program, "HIST14", handled Time at Level data. Printouts of both programs are presented in Appendix D.

A comprehensive list of Tables and Figures compiled from the Datamyte data is assembled in Appendix E. Heading this list is a performance summary for the four Real Time Rainflow operating periods during the season.

5.3.1 Real Time Rainflow - Shaft Thrust

The tables and figures in Appendix E, which present the data obtained from the shaft thrust signal, using the Real Time Rainflow Datamytes, are as follows:

TABLE	TITLE
E2-E7	Thrust Real Time Rainflow Two Dimensional Data

FIGURE	TITLE
E1a-E1d & E2a-E2b	Thrust Extreme Excursions Per Minute

Tables E2 to E7 list the two dimensional Real Time Rainflow, as collected by the Datamytes. The meaning of the data contained in Tables E2 to E7 is realized by studying Table E2. Column 2 of the table, is a measure of the amplitude of each half cycle, from the trough to the peak, in the number of Bins. The change in shaft thrust required to change the Datamyte level by 1 Bin is listed in the preamble text of Table E2. Column 3 is the number of the Bin within which the average of the peak and trough falls. Column 4 is a count of the number of times this range-mean combination was repeated during the testing period.

The data in Tables E2 to E7 was entered into the "HIST13" software program to produce histograms of the extreme excursions of the thrust signal from level zero.

The extreme excursions for each signal are calculated form the two dimensional Real Time Rainflow data as follows:

For each cycle counted by the Datamyte, one extreme excursion from the zero level exists. If the mean of the cycle is greater than zero, then the extreme excursion is the mean of that cycle plus one half the range of that cycle. If the mean of a cycle is less than zero, then the extreme excursion for that cycle is the mean of that cycle minus one half the range of that cycle. The Bin counter for the thrust or torque peaks histogram which corresponds to the level of the extreme excursion is then increased by the count of the number of times which that mean-range combination occurred.

The peak count histograms shown in Figures E1a-E1d and E2a-E2b are therefore a simplified method of presenting the Real Time Rainflow data. If however, the

Real Time Rainflow statistics are to be used for fatigue analysis of the components, the row two dimensional statistics as listed in Tables E2 to E11 should be used.

So that data collected during test periods of different lengths can be compared, the histograms in Figures E1a-E1d and E2a-E2b are plotted as the average peak excursions per minute, rather than the actual counts during the entire test period.

The data which produced Figures E1a-E1d was collected using a Datamyte with a hysteresis setting of 2. This hysteresis setting, caused the memory of the Thrust and Real Time Rainflow Datamyte to overflow before the end of each test period. In order to gather thrust Real Time Rainflow data for a greater percentage of each test period, another Real Time Rainflow Datamyte, this one with a hysteresis setting of 3, was installed to record thrust signal statistics. The Thrust Real Time Rainflow Datamyte with a hysteresis setting of 3 also overflowed its memory before the end of the second test period. This Datamyte did not record successfully for the third test period, but recorded successfully for the fourth test period, as shown in Table E1.

5.3.2 Real Time Rainflow - Shaft Torque

The tables and figures in Appendix E, Volume 2 which present the data obtained from the shaft torque signal, using the Real Time Rainflow Datamytes, are as follows:

TABLE	TITLE
E8-E11	Torque Real Time Rainflow Two Dimensional Data

FIGURE	TITLE
E3a-E3d	Torque Peaks Per Minute

Tables E8 to E11 list the two dimensional Real Time Rainflow, as collected by the Datamytes. This data was analysed by the same methods as given in Section 5.3.1. The program "HIST13" was again used, the only difference being that the torque signal was essentially always positive, whereas the thrust signal had both positive and negative values. This was taken into account in the installation of the torque Datamytes, so that the lower limit of Bin zero is not the value 0 kN, as for the thrust Datamytes, but the lower limit of Bin zero is 272 kN*m (the Datamyte Bins are numbered from -16 to +15). The comparisons of the torque data for the four test periods is also plotted, in Figures E3a-E3d, as counts per minute to facilitate comparison of the data from each period.

5.3.3 Time at Level - Shaft Thrust

The tables and figures in Appendix E, which present the data obtained from the shaft thrust signal, using the Time at Level, Plus Level Crossings Datamytes are as follows:

TABLE	TITLE
E12-E15	Thrust Time at Level Plus Level Crossing Counts

FIGURE	TITLE
E4a-E4d	Thrust Per Cent Time at Level
E5a-E5d	Thrust Per Cent Level Crossings

Tables E12-E15 list the Time at Level Plus Level Crossings data as it is output by the Datamytes. The histograms presented in Figures E4a-E4d and E5a-E5d are direct plots of the number in these tables. Figures E4a-E4d and 5A-5D were plotted by the program "HIST14", after entering the tabular data. An explanation of the meaning of each column in Table E12 is as follows:

Column 2 is the number of individual readings made by the Datamyte, which was within the limits of that Bin. Column 3 is obtained by dividing the number of times the level corresponded to each Bin (column 1), by the total number of readings made.

Column 4 is the number of times the signal level entered into that Bin, after satisfying the hysteresis criteria as described in Section 5.3. The hysteresis setting for the time at Level Plus Level Crossing Datamytes for both the torque and thrust signals, was 2, for all four test periods.

Column 5 is obtained by dividing each reading in column 4, by the total number of counts in column 4. Columns 6 and are the lower and upper bound, respectively, of each Bin.

5.3.4 Time at Level - Shaft Torque

The tables and figures in Appendix E, which present the data obtained from the shaft torque signal, using the Time at Level, Plus Level Crossings Datamytes, are as follows:

TABLE	TITLE
E16-E19	Torque Time at Level Plus Level Crossing Counts

FIGURE	TITLE
E6a-E6d	Torque Per Cent Time at Level
E7a-E7d	Torque Per Cent Level Crossings

The shaft torque statistics obtained by the Time at Level Plus Level Crossings Datamyte was also analysed using the methods described in Section 5.3.3.

5.3.5 Statistical Data Collected During Complete Season

The season shaft statistical data was obtained by combining the data for the four test periods. The Real Time Rainflow statistics were combined using the program "HIST13", while the Time at Level Plus Level Crossings statistics were combined using the program "HIST14". The data tables and histogram plots for the complete season data are presented in Appendix E. The format of the season torque and thrust data is the same as described in Sections 5.3.1 and 5.3.3.

5.3.6 Datamyte Statistics During Five Day Tests

The same Datamytes which were installed during the "Long Term Shaft Statistics Tests" Section 5.2, were connected during part of the 84-06-30 to 84-07-03 testing period. The Datamytes collected data during the following test periods:

- Test numbers 103 to 114
- Test numbers 116 to 147
- Test numbers 148 to 343

The shaft torque and thrust Real Time Rainflow and Time at Level Plus Level Crossing, statistics for these test periods are also given in Appendix E. All of these statistics are given as counts per minute and percent counts for ease of comparison with the long term shaft statistics contained in the same Appendix.

5.4 Motion Recording System

The Terra Technology DCS-302 Digital Cassette Seismograph digitally recorded three channels of data on a cassette tape at a scan rate of 100 readings per channel per second. The machine scanned all channels continuously but only recorded to magnetic tape when a signal exceeded preset internal levels, or when an external trigger signal was received. A built-in circular buffer memory allowed the machine to record on tape some data which preceded the actual event. In this installation, 1.92 seconds of data preceding the event was recorded on tape. Recording continued until approximately 20 seconds after the trigger criterion was no longer met.

The three channels of data comprised shaft torque, shaft thrust and ship speed. For the tests, an external analogue event detector was used to sense fast changes in the shaft torque signal and to provide an external trigger to the DCS-302 recorder. The analogue event detector used during the previous five day test period was again employed for this purpose. The installation was finalized by August 7 and became operational for the second of the four test periods.

The intention was to record examples of the largest torque peaks encountered during the season. Since each tape was only capable of holding a maximum of 40 event samples, it was desirable to set the threshold event detection level on the analogue event detector as high as possible without missing all events for a test period. During the first trial, from August 8 to September 5, the event threshold was set too high and therefore no events other than the ones recorded during equipment setup were detected. For the next two test periods, the threshold limit was lowered and a member of the ship's crew was assigned to change the tape at mid term.

The data cassettes were transported to Calgary at the end of each test period and analysed using a Terra Technology SMR-102 reproduction unit. This unit reproduced the original voltages recorded in the form of a strip chart. The following information was also printed on the strip chart, for each event:

- Julian day data was recorded
- Hour
- Seconds
- User entered number
- Gain of each channel during data recording
- Serial number of recording unit
- Event number

The gain of the output signal was determined by noting the gain used during recording and the scale of the calibration signals printed at the beginning of each strip chart. The scale for the three signals reproduced by the SMR-102 unit are:

- Shaft torque - 136 kN.m/volt
- Shaft thrust - 1,150 kN/volt
- Ship Speed - 10 knots/volt

5.4.1 Presentation and Analysis of the DCS-302 Recorded Data

A log of the events recorded by the DCS-302 is given in Appendix F. This Appendix consists of 5 tables, one for each tape recorded. The tables contain the following information for each event:

Column 1 is the number of the event for that tape. Column 2 is the Julian day which the recording was made. Column 3 is the equivalent date. Column 4 is the time of the recording. Column 5 is the mean voltage of the torque signal during the recording. Column 6 is the peak voltage of the torque signal. Column 7 allows comments on the event.

The values in Columns 5 and 6 were scaled off from the trace of the torque signal. The mean and peak voltages can be converted to engineering units using the scale factor of:

Torque = 136 kN*m/Volt.

The recordings made by the DCS-302 digital recorder failed to provide information on any torque peaks larger that the largest recorded during the five day test period. The largest torque peak recorded by the DCS-302 recorder by 269 kN*m, which is less than the 299 kN*m torque peak recorded during event number 117. Since there are more channels of data available from the five day test period, the analysis of individual events has been confined to the 343 events recorded during this period.

5.5 The Ship's Log

As part of the MV Robert LeMeur long term shaft statistics analysis, the ship's log was examined in an effort to determine the operational mode (underway, icebreaking or stationary) and the corresponding ice conditions for the same period. The information was then related to the shaft torque histogram, Figures E3, E6 and

E7 to provide an assessment of the ice conditions which produced the measured loads.

Descriptions of operational mode and ice conditions were taken from the ship's log for each period. Entries in the log were generally made every four hours unless a specific activity occurred during that time which was then individually documented. The operational mode was divided into three basic categories: stationary; underway, and; icebreaking. The operational mode was noted to the nearest hour or half-hour segment as were the corresponding ice conditions. Ice conditions were categorized as first year, second year, multi-year, new ice or open water. Ice concentrations were given in tenths. Also noted were remarks found in the log such as: heavy ridging; rotten ice; floe size, or; heavy impact.

5.5.1 Presentation and Analysis fo the Ship's Log Data

The data extracted from the log is detailed in Tables 5.5.1-1 and 5.5.1-2. The four data collection periods are approximately equivalent to the months of July, August, September and October. The time is categorized according to operational mode and is given as a percentage of the total time. Time periods for breaking ice and underway are further divided according to the percentage of time in various ice conditions, and the percentage of time and hours specifically in ice. The total time operating in ice, as a percentage of the total operating time (ie. not stationary) is 59.2% in July, 53.9% in August, 47.9% in September and 74.5% in October. The seasonal average for 1984 is therefore 58.9%.

The results of the ship's log analysis indicate that the ice conditions for the operating season of 1984 were more severe than normal. July and August had similar ice conditions with concentrations of second and multi-year ice averaging 1 to 3/10, significantly higher than the norm of 0 to 1/10. The ice conditions for September were also more severe with 100% of the ice encountered by the MV Robert LeMeur having some second or multi-year ice included. The ice conditions for October were normal with new ice forming during the first week. By the end of October, the ice cover averaged 8-10/10 grey-white.

	1		2		3		4	
PERIOD NUMBER	Hr.	%	Hr.	%	Hr.	%	Hr.	%
Total Time Period	808.0	100.0	648.0	100.0	654.0	100.0	638.0	100.0
Time In Stationary Mode	369.5	45.7	277.6	42.8	467.2	71.4	266.6	41.8
Time In Operational Mode	438.5	54.3	370.4	57.2	186.8	28.6	371.4	58.2
Time In Operational Mode In Ice	259.4	32.1	199.8	30.8	89.3	13.6	276.8	43.4
Time Breaking Ice	241.2	29.8	187.1	28.9	58.6	9.0	243.6	38.2
Time Breaking Ice In Ice	193.0	23.9	149.8	23.1	46.9	7.2	195.1	30.6
Time Underway	197.3	24.4	183.3	28.3	128.0	19.6	127.8	20.0
Time Underway In Ice	66.4	8.2	50.0	7.7	42.4	6.5	81.7	12.8

Time Breaking Ice + Time Underway = Time in Operational Mode

Time Breaking Ice In Ice + Time Underway In Ice
= Time in Operational Mode In Ice

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MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE: SUMMARY OF OPERATIONAL AND STATIONARY TIMES FOR THE FOUR LONG TERM TEST PERIODS

TABLE No. 5.5.1-1

	Time Breaking Ice								Time Underway							
	Percent of Time Breaking Ice (%)				Percent of Time Breaking Ice Spent In Ice (%)				Percent of Time Underway (%)				Percent of Time Underway Spent In Ice (%)			
Period Number	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Ice Conditions																
1 - 2/10	5.6	12.6	0	0	4.5	10.1	0	0	13.2	31.0	0	0	2.0	4.7	0	0
3 - 4/10	6.0	11.7	0	0	4.8	9.4	0	0	10.3	8.6	0	0	3.6	3.0	0	0
5 - 6/10	7.0	0.7	0	0	5.6	0.6	0	0	4.7	2.2	0	0	2.6	1.2	0	0
7 - 8/10	10.6	10.8	0	0	8.5	8.6	0	0	5.7	2.4	0	0	4.3	1.8	0	0
Very Rotten	3.4	0	0	0	2.7	0	0	0	21.3	0	0	0	10.7	0	0	0
1st year with up to 1/10 second year	53.8	11.2	39.6	19.7	43.0	9.0	31.7	15.8	18.0	15.1	22.1	4.3	9.0	7.6	11.1	2.2
1st Year with 2/10 or more second year	3.4	51.2	60.4	0.9	2.7	41.0	48.3	0.7	2.7	17.9	43.9	0.7	1.4	9.0	22.0	0.4
1st year with significant ridging	10.3	1.8	0	0	8.2	1.4	0	0	0	0	0	0	0	0	0	0
Nilas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1 - 2/10 Grey-White	0	0	0	0	0	0	0	0	0	0	0	7.2	0	0	0	1.1
3 - 6/10 Grey-White	0	0	0	2.6	0	0	0	2.1	0	0	0	2.6	0	0	0	1.2
7 - 10/10 Grey-White	0	0	0	75.5	0	0	0	60.4	0	0	0	69.5	0	0	0	59.1
White	0	0	0	1.4	0	0	0	1.1	0	0	0	0	0	0	0	0
Open Water	0	0	0	0	0	0	0	0	24.2	22.8	34.1	15.7	0	0	0	0
Equivalent Total Hours (Hours)	241.2	187.1	58.6	243.6	241.2	187.1	58.6	243.6	197.3	183.3	128.0	127.8	197.3	183.3	128.0	127.8

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TITLE: SUMMARY OF OPERATIONAL MODE AND ICE CONDITIONS FROM THE LOG OF THE M.V. ROBERT LEMEUR FOR THE FOUR LONG TERM TEST PERIODS

TABLE 5.5.1-2

5.6 Analysis of Datamyte Statistics

From the histograms in Appendix E, Volume 2 Figures E1 to E7, it can be seen that the ship worked the hardest during the second data collection period, which corresponds approximately to the month of August. The ship was operating at lower power levels during the third test period, than during the other three test periods.

An initial review of the log shows a smaller percentage of the time spent in a stationary mode than the percentage of time as determined from the Datamyte data. This discrepancy is due to the difference in frequency of observations of operational mode, made by the Datamytes and the ship's bridge personnel. The ship's log entries do not include short periods (in the order of minutes) when the shaft is not operating. There are also periods with the ship underway or breaking ice using only the port propeller. Because the instrumentation is located on the starboard shaft, the Datamyte registers stationary while the ship's log indicates some activity. Although such periods of inactivity are short, each is registered by the Datamyte and the cumulative total is substantial. As a result, the percentage of time that the ship is in a stationary mode is thought to be accurately represented by the Datamyte data and the data extracted from the ship's log is adjusted accordingly.

The data for July and August are similar as are the ice conditions and general operations for the two months. The torque statistics indicate that the percentage of operating time attributed to ice/propeller interactions is 6.3% for July and 8.9% for August. The peak shaft torque registered for July and August is 323 - 340 kN.m.

The torque histogram for September shows 0.16% of the operational time spent in ice/propeller interactions. The peak torque is 272 - 284 kN*m. These relatively low values are probably a result of the decision to continue icebreaking activities but with less vigour and more caution due to some minor hull damage. The MV Robert LeMeur spent the last two weeks of September in drydock having the damage repaired. This is reflected in the high proportion of stationary time registered by the Datamytes. It is likely that the reduced amount of ice/propeller interaction in September and the lower ice forces were a result of operational decisions.

The shaft torque histogram for October indicates that 1.2% of operational time is ice/propeller interactions. The peak force for October is lower than that of July and August, 272 kN*m versus 323 kN*m, primarily because of new ice, grey-white and therefore significantly softer.

Figure 5.6-1 is a histogram of the mean torque levels of the events recorded during the June 30 - July 3 test period which had some ice/propeller interaction. This plot shows that the mean torque level was generally greater than 102 kN*m when events occurred. The shaft statistics provides a means of estimating the number of ice/propeller interactions per minute while the ship is operating in ice, for the whole season. The assumption is made that the majority of events occur when the mean torque level is greater than approximately 100 kN*m and that a significant event occurs when the shaft torque changes by more than 25% of mean torque.

The two dimensional shaft torque Real Time Rainflow data has been reviewed for each of the four recording periods using the previous assumption of what constitutes an event. The results, converted to events per minute, while operating in ice, are shown in Table 5.6-1.

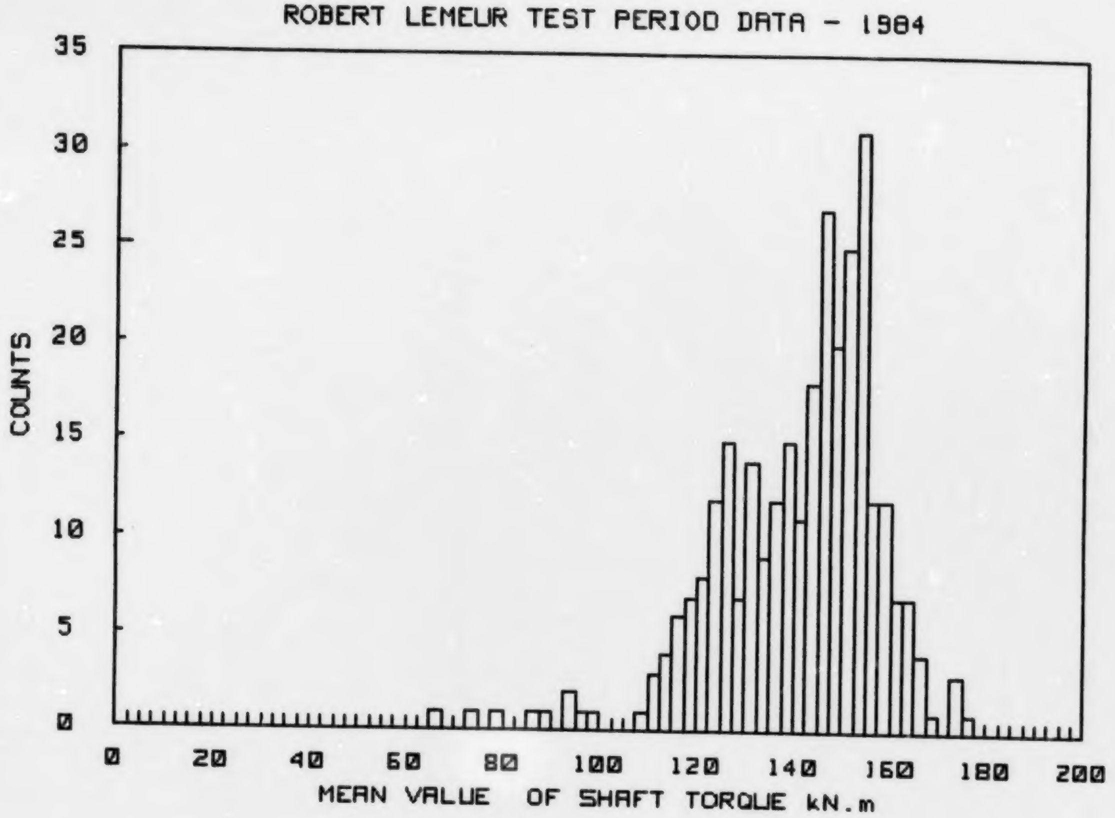
The specific readings of interest for the whole season are:

- Maximum shaft compression - 1,296 to 1,440 kN
- Maximum shaft tension - 1,008 to 1,152 kN
- Maximum shaft torque - 323 to 340 kN*m
- Percent time shaft stopped during season - 50.25

The maximum shaft compression measured represents a thrust level approximately 4.8 times the nominal shaft thrust. The maximum shaft torque measured represents a torque level approximately 2.0 times the nominal shaft torque. These values compare with the values obtained for the 343 detailed tests of:

- Maximum shaft compression - 1,132 kN
- Maximum shaft tension - 475 kN
- Maximum shaft torque - 301 kN*m

Figure 5.6-2 shows a plot of the number of level crossing counts for shaft thrust during the 1984 season. The level crossing counts are used, as opposed to the number of thrust peaks, because the thrust peak data does not cover an entire season due to the memory overflow problems. From Figure 5.6-2, it can be seen that on a semilog plot, there is no tendency for the shaft thrust to approach limiting values. It is expected that if the



TOTAL NUMBER OF DATA POINTS PASSING TESTS IS: 301
THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:140.86
AND ITS STANDARD DEVIATION IS:16.893

DATA SATISFIED THE FOLLOWING TEST(S)

FIRST TYPE OF TYPE OF INTERACTION > 0

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: MEAN SHAFT TORQUE DURING ACTUAL EVENTS RECORDED 84-06-30 TO 84-07-03 HISTOGRAM
		FIGURE No. 5.6-1

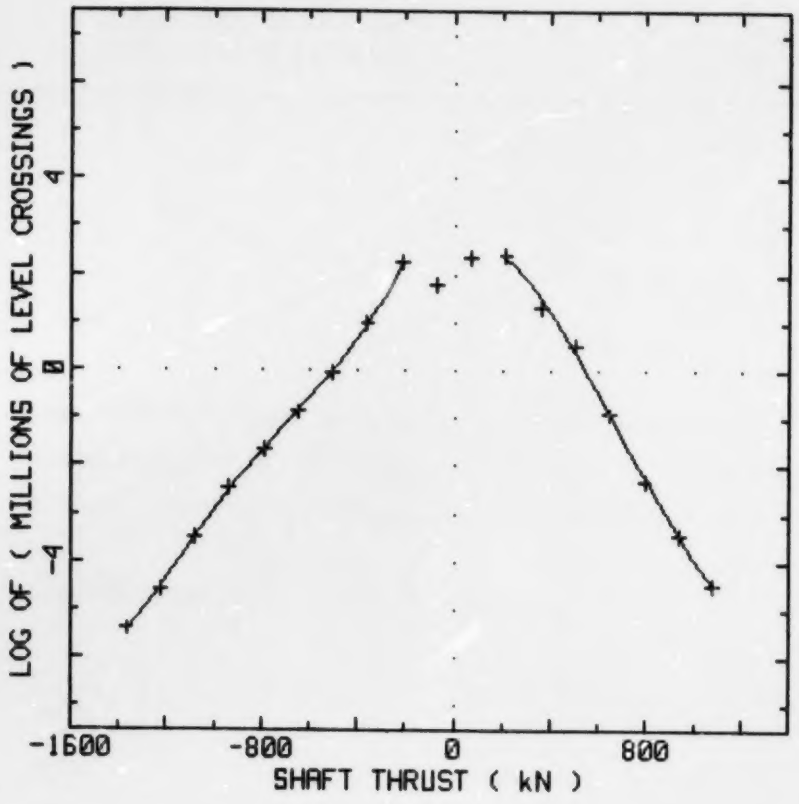
Time Period	Time Spent (Min)[1] Operating in Ice	Number of IPI[2] Events	Rate of IPI Events Per Minute
July	15,564	64,921	4.17
August	11,988	82,899	6.92
September	5,358	11,407	2.13
October	16,608	58,842	3.54

1. From analysis of ship log data, see Section 2.0

2. IPI means: ice/propeller interactions. Based on counting shaft torque variations with a mean or greater than or equal to 102 kN * m and with a range of greater than or equal to 25% of the mean torque.

TITLE: NUMBER OF ICE PROPELLER IMPACTS AS DETERMINED FROM LONG TERM "REAL TIME RAINFLOW" STATITICS OF SHAFT TORQUE COLLECTED BY THE DATAMYTE

TABLE No. 5.6-1



CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **LEVEL CROSSING COUNTS FOR SHAFT THRUST DURING 1984 SEASON PLOT**

FIGURE No. 5.6-2

statistics of the shaft thrust signal were recorded for many seasons, then larger thrust excursions from the mean would be measured.

Figure 5.6-3 is a plot of the level crossing counts for the shaft torque signal during the 1984 season. This plot has a tendency to trail off on a semilog plot. It is felt that the shaft torque, therefore, does have a possible upper bound. In practice, this upper bound is probably a function of the shaft clutch kick-out criteria.

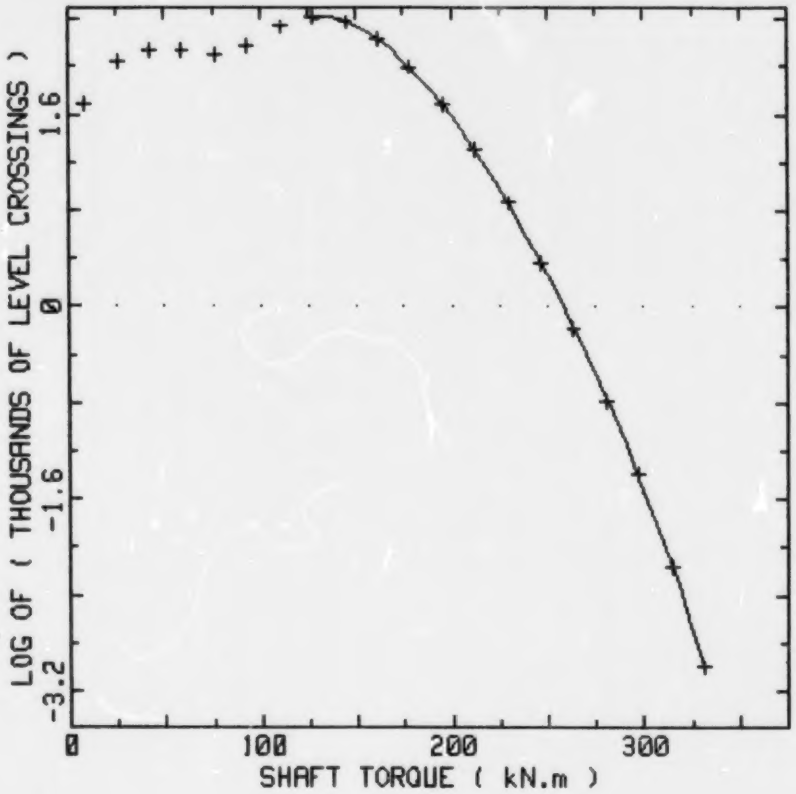
Turning to the 5 day test data, it can be seen that the shaft thrust statistics during the 84-06-30 to 84-07-03 test period are not representative of the shaft thrust statistics recorded during the 84-07-04 to 84-10-29 test period. The maximum shaft compression in the range of 1,440 kN to 1,583 kN compares with the maximum shaft compression during the season test period in the range of 1,296 kN to 1,440 kN. The maximum shaft tension in the range of 288 kN to 432 kN is less than the maximum shaft tension during the season test period in the range of 1,008 kN to 1,152 kN. The maximum shaft torque of 323 kN*m to 340 kN*m compares with the same results for the season test period. The maximum shaft torque occurred during the period when the starboard shaft clutch kicked out automatically due to slippage. The percent of stopped time for the starboard shaft varies between 30 and 80 percent while the average percent of stopped time for the shaft during the season is 50.25 percent.

Using the same criteria for the number of ice/propeller interactions per minute (IPI/Min) during the test period as is used for interactions during the season yields the following results:

- For test numbers 103 to 114 - 2.2 IPI/Min
- For test numbers 116 to 147 - 2.4 IPI/Min
- For test numbers 148 to 343 - 6.1 IPI/Min

These numbers compare with the monthly counts of IPI/Min, which vary between 2.13 IPI/Min and 6.92 IPI/Min.

The different Datamyte recordings for the period 84-06-30 to 84-07-03 which cover the same sets of tests cannot be compared directly. This is due to numerous shutdowns of the individual Datamytes at different times resulting in records which cover less time than the duration of the testing period.



EQUATION OF PLOTTED LINE

$$\log(Y/1E3) = -2.212665E{-}09 + X^4 + 2.099041E{-}06 + X^3 - 8.340003E{-}04 + X^2 + 1.309154E{-}01 + X - 4.487115$$

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: LEVEL CROSSING COUNTS FOR SHAFT TORQUE DURING 1984 SEASON PLOT** **FIGURE No. 5.6-3**

5.7 Summary of Shaft Statistics

The shaft torque and shaft thrust, maximum signals recorded during the full season were larger than the maximums recorded during the 343 detailed tests, by the following:

- Maximum shaft compression 21 percent larger
- Maximum shaft tension 127 percent larger
- Maximum shaft torque 10 percent larger

5.8 Conclusions

Since the maximum shaft torque and shaft compression, measured during the 343 detailed tests were within 10 percent and 21 percent respectively, of the maximums measured during the entire season, the 343 detailed tests represent good data for analysis of the maximum ice loads encountered during normal ship operations. Since the ice conditions for the 1984 season were more severe than normal, the 343 detailed tests are a good indication of the maximum ice loads likely to be encountered by this vessel.

The data recorded for astern maneuvers during the 343 detailed tests is not representative of the percent of time spent travelling astern. This can be seen by comparing the Datamyte thrust statistics for the 343 detailed tests with the season statistics. However, since the largest shaft thrusts occur during forward thrust, the relatively small number of detailed accounts of astern thrusts is not important.

As the Datamyte statistics cover a large portion of the normal operating season, the shaft torque and thrust statistics would be very useful in predicting the fatigue life of the propulsion system components.

6. GENERAL CONCLUSIONS

6.1 Blade Forces

The maximum magnitude of the recorded blade force was 5.3 times the maximum calculated steady state hydrodynamic load at bollard condition.

Water loads, induced by the ice are a significant component of the total load on the blade. Water loads induced during blockage events were 85% of the maximum ice impact loads.

Locations of the high blade forces are near the mid height of the blade at r/R = 0.7. Smaller forces were located at higher radiae.

Circumferentially, forces appear to be located about the middle of the blade chord, forward of the locations of the hydrodynamic steady state location. These locations however are suspect. It is not understood how an ice load can be applied at the middle of the chord length without being first broken off by the blade.

Most of the impact forces were directed forward. However, a number of impacts resulted in the blade force being directed aft.

Blade impacts lasted, on the average 0.063 seconds. The maximum durations was 0.179 second. Blade impact durations are compatible with the time of blade passing the ice.

The larger the force, the shorter the impact durations.

Short, single impact produced the highest blade force recorded.

Masses of ice blocks derived from the impulse analysis are of the order of 30 to 1,200 Kg.

Blade instrumentation did not pick up in-plane-forces.

An increase of shaft RPM leads to an increase of the blade impact forces.

For the small changes in pitch angle θ ($16° < \theta < 28°$) there is no appreciable change of the blade forces. Smaller pitch angle settings lead to a drastic reduction of the impact forces. Astern pitch produced very small forces.

Rudder angle to port lead to the increase of the frequency and severity of blade impact forces.

Ship's speed does not influence the magnitude of the blade impact forces.

The maximum value of the blade bending moment was 310 kN*m, which is approximately 6 times larger than the calculated blade bending moment in bollard condition.

The highest bending moments occurred during the single events, of very short duration.

Stresses in the blade due to the maximum bending moment were estimated to exceed yield on the compression side of the blade.

6.2 Shaft Torque

The maximum torque recorded was twice the nominal shaft torque of 151 kN * m. It was recorded during a milling event.

High torque levels are associated with low shaft thrust levels.

The maximum torque acting on one blade was 5 times the steady state hydrodynamic torque.

Average duration of torque events was 2.0 sec.

Maximum torque lasted 0.55 sec.

Maximum blade forces occurred during the short torque event durations.

6.3 Shaft Thrust

The maximum thrust recorded was 1150 kN which is 4.5 times the calculated bollard thrust.

6.4 Locations of the Ice Impact Forces

Majority of ice events occurred at 45° and 235° measured counter-clockwise from 12 o'clock position.

Shaft skeg creates a "shadow" effect, particularly at high vessel speed where no interaction takes place.

6.5 Ice Interaction Model

Ice-Blade Interaction phenomena, described in Milestone 1 were only partially verified throughout the test programme. The magnitudes of blade forces predicted were confirmed. However, the directions of the force vector were not. Number of parameters constituting the analytical model were not verified. Therefore a new, simplified model was developed, accounting only for those parameters which were extracted from the tests.

6.6 Blade Model

Stresses calculated by using simple beam theory were found to be compatible with those measured during the calibration tests. An assessment of the dynamic behaviour of the blade showed the dynamic magnification (or diminution) is an important parameter, that especially for high impact forces.

6.7 Shaft and Thrust Models

The models developed were a reasonable representation of the real system. The predicted peak shaft torque and thrust torque response are within 15% of the measured values.

The models were a useful tool in helping to estimate the magnitude of ice loads on the propeller.

The models helped determine the number blades that hit the ice, and the type of event that occurred.

During the time period from the start of the response until the peak, both model outputs were approximately the same as the measured response. After this period, various parameters changed (propeller pitch, fuel rack, propeller/ice interaction) resulting in some discrepancy in the last part of the model's response waveform.

6.8 Yoke Pin Model and Friction Factor

Approximately 90% of the spindle torque experienced by the blade may be transmitted as force to the sliding block/yoke pin.

Maximum values of blade spindle torque and sliding block loads cannot be measured accurately from the servo oil pressure sensor due to friction in the pitch change mechanism.

6.9 Shaft Movement Results

There is a greater tendency for horizontal motion than vertical motion of the shaft in the aft stern-tube bearing.

The motion is erratic and is forced at the blade passing frequency.

The shaft may contact any area of the bearing surface, whether on the lower or upper surfaces, as a consequence of the vibratory impulses imposed during ice/propeller interaction.

The performance of the bearing, even at the essentially constant RPM of this test project, is outside the predictive capability of the standard hydrodynamic bearing theory.

6.10 Long Term Shaft Statistic

Since the maximum shaft torque and shaft compression, measured during the 343 detailed tests were within 10 percent and 21 percent respectively, of the maximums measured during the entire season, the 343 detailed tests represent good data for analysis of the maximum ice loads encountered during normal ship operations.

Since the ice conditions for the 1984 season were more severe than normal, the 343 detailed tests are a good indication of the maximum ice loads likely to be encountered by this vessel.

The data recorded for astern maneuvers during the 343 detailed tests is not representative of the percent of time spent travelling astern, due to many more astern manuvers during the complete season.

As the Datamyte statistics cover a large portion of the normal operating season, the shaft torque and thrust statistics would be very useful in predicting the fatigue life of the propulsion system components.

7. RECOMMENDATIONS

7.1 General

Preliminary data analysis has indicated significant departure from the previous understanding of ice interaction phenomena for a shrouded propeller. The issue of such importance warrants more in-depth analysis in order to fully understand and justify these findings.

The amount of data available from the test program is of such magnitude and diversity that only a smothering of the analysis potential has been accomplished. Large gaps in the analysis exist which require closing to develop the complete picture. In particular cross-correlation of the measured variables is required to strengthen the conclusions.

The analytical effort should be continued without a break. The timing is opportune because of the availability of the principal participants from the current study.

7.2 Propeller Blade

Further study is necessary to quantify the influence of dynamics reference of ice interaction with a blade.

Research into the influence of water on maximum blade loading must be analysed from the test data in order to allow scaling factors to be established for application to other vessels.

Life cycle fatigue analysis of the blade and hub components should be undertaken in order to predict the onset of fatigue of failure.

Stress analysis of the blade under the yield causing bending moments should be conducted in order to verify the preliminary findings.

7.3 Shaft Bearing

The test results require further study to determine:

- Scaling factor and zero offsets for the traces
- Misalignment data
- Acceleration forces created by radial displacement of the shaft

A bearing model should be developed capable of explaining as far as possible, the findings of these field results.

7.4 Propulsion Train

The development of more detailed models to incorporate ice/propeller interaction and machinery parameters, preferably finite element models should be undertaken. These models should eliminate the approximations made with the existing models, and be made general enough for applications to other vessels.

A statistical analysis should be performed on the thrust and torque estimates from the above models.

A series of propeller torque and thrust wave forms during ice interaction should be generated for design purposes.

A study should be done on the feasibility of incorporating mathematical models that predict propeller loads from shaft measurements, for use in regulations and preventative maintenance programs, for propulsion systems operating in ice.

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TP 6840E
MEASUREMENT OF ICE/PROPELLER INTERACTION PARAMETERS - MV ROBERT LEMEUR
APPENDICES TO MAIN REPORT

PREPARED FOR THE TRANSPORTATION
DEVELOPMENT CENTRE

BY: J. DUFF
K. KIRBY
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CANADIAN MARINE DRILLING LTD.
CALGARY, ALBERTA
AUGUST, 1985

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17. Abstract

This report documents the preliminary analysis of the data collected on board the M.V. Robert LeMeur during the 1984 operating season, including five days of dedicated tests in June 1984. Analysis of the propulsion train components is performed. Propeller ice impact forces are analyzed and the response of the shafting system is determined. A model of blade-ice interaction is proposed based on the data analysis. A model of the yoke-pin and shaft response to the ice torque and thrust is also developed. Software used during data analysis is fully documented. Conclusions pertinent to regulatory purposes are derived.

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17 Résumé

Ce rapport rend compte des résultats de l'analyse préliminaire des données recueillies à bord du Robert-LeMeur au cours de la saison d'exploitation 1984, y compris les cinq journées consacrées aux essais spécialisés en juin de cette année. L'analyse a porté sur les organes de la chaîne cinématique et, notamment, sur les chocs subis par les pales d'hélice et leurs répercussions sur la ligne d'arbres. Un modèle de l'interaction glaces/pales est proposé, fondé sur l'analyse des données, ainsi qu'un modèle figurant la tenue de l'arbre et de la goupille d'accouplement au couple de torsion et à la poussée résultant de cette interaction. Les logiciels utilisés sont décrits en détail. Sont enfin présentées des conclusions intéressant la réglementation actuelle et celle à venir.

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SOURCE: CANMAR

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HSDAR4_5 111
BLADE_CAL3 125

```
5       !       ANALYZE4_1
10      !       ANALYSIS OF ICE PROPELLER INTERACTION DATA
15      !
20      !       WRITTEN BY: DOUG MONTGOMERY
25      !       DATE: MAY 22, 1984
30      !       VERSION: 1.0
35      !
40      !       MODIFIED BY:PAUL SPENCER
45      !       DATE:JUNE 25 1984
50      !       VERSION:ANALYZE2
55      !       REASON:TO MATCH DATA AQUISITION PROGRAMME "RLDAR4"
60      !
65      !       MODIFIED BY:PAS
70      !       DATE:84/08/21
75      !       VERSION:3.0
80      !       REASON:I FELT LIKE IT
85      !
90      !       MODIFIED BY: KEN KIRBY
95      !       DATE: 84-11-11
100     !       VERSION: 3.0
105     !       REASON: TO ALLOW CONVERTED WURMLINGER CALIBRATION DATA DISKS TO BE
110     !               READ AND PLOTTED PROPERLY
115     !
120     !       MODIFIED BY: KEN KIRBY
125     !       DATE: 84-11-26
130     !       VERSION: 3.3
135     !       REASON: PUT IN A HELP MANUAL
140     !               X-Y PLOTTING FOR A GIVEN TIME PERIOD
145     !               FIX THE TAPE READING ROUTINE
150     !               AND TO MAKE THE START EASIER
155     !
160     !       MODIFIED BY: KEN KIRBY
165     !       DATE: 84-12-18
170     !       VERSION: 3.4
175     !       REASON: FIX Y-SCALE LABLING FOR PLOTS WITH A Y-RANGE OF LESS THAN 1
180     !
185     !       MODIFIED BY: KEN KIRBY
190     !       DATE: 84-12-20
195     !       VERSION: 3_4
200     !       REASON: FIX START AND END TIMES OF PROBE DISPLACEMENT PLOTS
205     !               FIX MOVE CURSOR ROUTINE FOR DISPLACEMENT PROBE PLOTS
210     !               PUT HEADINGS ON PROBE PLOTS
215     !
220     !       MODIFIED BY: KEN KIRBY
225     !       DATE: 85-01-10
230     !       VERSION: 3_4
235     !       REASON: TO CORRECT THE GAIN ON THE TORQUE CHANNEL BY 1.5
240     !
245     !       MODIFIED BY: KEN KIRBY
250     !       DATE: 85-01-14
255     !       VERSION: 3_4
260     !       REASON: TO FIX CHANNEL DESIGNATIONS AND GAINS FOR
265     !               TEST NUMBERS 1 TO 13
270     !
275     !       MODIFIED BY: KEN KIRBY
280     !       DATE: 85-01-30
285     !       VERSION: 3_6
290     !       REASON: TO PUT IN NEW SLIDING BLOCK GAINS AND OFFSETS
295     !               AND NEGATIVE PROPELLER PITCH GAINS
300     !
305     !       MODIFIED BY: KEN KIRBY
310     !       DATE: 85-02-05
315     !       VERSION: 3_7
320     !       REASON: TO ALLOW THE LOAD LOACATION STATISTICS TO BE OUTPUT TO
325     !               A TABLE. THIS TABLE IS THEN ADDED TO CHANNEL 30 OF THE
330     !               STATS DISK USING THE PROGRAM 'BLADESTAT1'
```

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **"ANALYZE 4 - 1"**

APPENDIX A

```
335   !            PREVIOUS INTERACTION STATISTICS HAD BEEN ADDED TO THE
340   !            STATSDISC ( D7 ) BY THIS METHOD USING THE PROGRAM
345   !            'ANALYZE3_2' AND TRANSFERRING THE DATA TO THE STATSDISC
350   !            USING 'BLADESTATS'.
355   !            FIXED 'FIND_MIN_MAX' ROUTINE. IT DID NOT INCLUDE SCALE
360   !            FACTORS
365   !
370   !    MODIFIED BY: KEN KIRBY
375   !    DATE: 85-02-09
380   !    VERSION: ANALYZE3_7
385   !    REASON: TO FIX COMMENTS FOR CHANNEL # 23
390   !            TO FIX THE FILTERED CHANNEL # 28
395   !            ALSO PROGRAM CHECKS FOR BAD DATA AT THE END OF THE RECORDS
400   !            CAUSED BY A PROBLEM WITH THE DATA ACQUISITION PROGRAM.
405   !            TO CHECK FOR BAD DATA, THE PREVIOUS DISK MUST BE READ FIRST.
410   !
415   !    MODIFIED BY: KEN KIRBY
420   !    DATE: 85-02-09
425   !    VERSION: ANALYZE3_8
430   !    REASON: TO FIND RADIAL AND CIRCUMFRENTIAL LOCATIONS OF IMPACT
435   !            AT TIME OF PEAK BLADE FORCE, USING BATCH MODE;
440   !            AND AT THE SAME TIME GET NEW MIN MAX AND MEANS
445   !            FOR THE STATSDISK USING ONLY THE GOOD DATA AND THE PROPER
450   !            CHANNEL GAINS AND OFFSETS.
455   !
460   !    MODIFIED BY: KEN KIRBY
465   !    DATE: 85-02-11
470   !    VERSION: ANALYZE3_8
475   !    REASON: TO FIX CALCULATION OF MIN AND MAX WHEN SLOPE < 0
480   !
485   !    MODIFIED BY: KEN KIRBY
490   !    DATE: 85-02-12
495   !    VERSION: ANALYZE3_8
500   !    REASON: TO FIX THE PLACEMENT OF THE SHAFT SPEED INTO CHANNEL 34
505   !            AND TO ADD ROUTINES TO THE BATCH MODE FOR RECOGNIZING
510   !            AN EVENT FROM THE SHAFT THRUST SIGNAL AND GIVE THE START,
515   !            PEAK, AND END TIMES IN sec. TO THE STATS DISK IN CHANNEL 25
520   !            THE CORRESPONDING THRUST IN CHANNEL 26 AND TORQUE IN CH. 27
525   !            THE TIMES OF EVENTS FOR SHAFT TORQUES ARE PLACED IN CH. 28
530   !            THE CORRESPONDING THRUSTS ARE IN CHANNEL 29 AND THE TORQUES
535   !            ARE PLACED IN CHANNEL 30.
540   !            ALL OF THIS INFORMATION IS STORED ON THE STATS DISK. SOME
545   !            CHANGES HAD TO BE MADE TO THE STATSDISK AND CHANNELS MOVED.
550   !            THIS NECESSITATED: MOVING THE RADIAL, CIRC. AND FORCE SENSE
555   !            TO CHANNEL 11;
560   !            MOVING THE TYPES OF INTERACTION TO CHANNEL 14;
565   !            MOVING THE INTERACTION #,ICE or WATER AND DIR. TO CH.15;
570   !            THE SHAFT SPEED WAS MOVED TO CHANNEL 22;
575   !            BLADE ORIENTATION PEAK,AND IMPACT DURATION TO CH.23, AND;
580   !            EVENT DURATION TIME AND INTERACTION ENERGY TO CH.24.
585   !            A NEW VERSION OF THE PROGRAM WHICH TRANSFERS THE
590   !            INTERMEDIATE STATS TO THE STATSDISK, 'STATDISC4' WAS WRITTEN
595   !            AND A NEW VERSION OF THE STATALYZE PROGRAM, 'STATALYZE7' WAS
600   !            WRITEN. THE NEW STATSDISK IS # K7.
605   !
610   !            AND PUT OFFSET ON THRUST SIGNAL
615   !
620   !    MODIFIED BY: KEN KIRBY
625   !    DATE: 85-02-15
630   !    VERSION: ANALYZE4_0
635   !    REASON: TO ADD TWO NEW A_MATRIX AND PUT IN SIGNAL OFFSETS
640   !
645   !    MODIFIED BY: KEN KIRBY
650   !    DATE: 85-02-20
655   !    VERSION: ANALYZE4_1
660   !    REASON: TO HARD CODE IN THE NUMBER OF GOOD SCANS FOR THE TEST DATA
```

```
665  !
670  !     MODIFIED BY:
675  !     DATE:
680  !     VERSION:
685  !     REASON:
690  !
695  ! PROGRAM NAME IS "ANALYZE3_8"
700  ! THIS PROGRAM IS WRITTEN FOR A H.P 9836 DESKTOP COMPUTER
705  ! WITH 1.79 MBYTE OF MEMORY,RECOMMENDED PRINTER H.P 9876A
710  ! FOR READING MAGNETIC TAPES YOU WILL REQUIRE AN INNOVATIVE
715  ! DATA TECHNOLOGY #GPIB1050 TAPE READER.
720  ! PROGRAM WRITTEN IN BASIC 2.1
725  ! TO LOAD BASIC 2.1 : PUT BASIC 2.0 DISK INTO RIGHT HAND DRIVE
730  ! AND TURN ON POWER TO COMPUTER,THIS WILL LOAD BASIC 2.0
735  ! TO LOAD  2.1 PUT DISK CONTAINING 2.1 INTO RIGHT HAND DISK DRIVE
740  ! AND TYPE  'LOAD BIN "AP2_1"' AND THEN HIT THE EXECUTE KEY.
745  ! TO LOAD THIS PROGRAM PUT DISK CONTAINING  THIS PROGRAM INTO RIGHT
750  ! HAND DISK DRIVE AND HIT THE SOFT KEY CALLED LOAD ,THEN TYPE IN THE
755  ! CURRENT PROGRAM NAME AND THEN HIT THE EXECUTE KEY.AFTER PROGRAM IS
760  ! LOADED HIT THE RUN KEY.LOTS OF LUCK FELLA!
765  !
770  !
775   OPTION BASE 1
780   GCLEAR
785   Total_channels=35
790   INTEGER Baseline(18)               ! BASELINE VALUES OF CHANNELS
795   ALLOCATE Channel_desc$(1:Total_channels)[35]         ! DESCRIPTION OF
                                                              DATA CHANNELS
800   ALLOCATE Channel_com$(1:Total_channels)[35]         ! COMMENTS ABOUT
                                                             DATA CHANNELS
805   ALLOCATE REAL Slope(Total_channels)   ! 'M' OF DATA CHANNELS
810   ALLOCATE REAL Offset(Total_channels)   ! 'b' OF DATA CHANNELS
815   INTEGER Current_record              ! CURRENT PLOTTING RECORD NUMBER
820   INTEGER Rpm(0:50)                   ! SHAFT SPEED BETWEEN PULSES IN R.P.M.
825   INTEGER Rpm_pulse(0:50)             ! RECORD NUMBER OF PULSES
830   INTEGER Numb_of_pulse               ! NUMBER OF PULSES
835   INTEGER Rpm_channel                 ! CHANNEL # OF SHAFT
840   INTEGER Channels                    ! NUMBER OF CHANNELS OF DATA
845   INTEGER Shaft_speed                 ! CURRENT SHAFT SPEED IN R.P.M.
850   INTEGER Channel_x                   ! CURRENT X CHANNEL BEING PLOTTED
855   INTEGER Channel_y                   ! CURRENT Y CHANNEL BEING PLOTTED
860   INTEGER N_channels                  ! NUMBER OF CHANNELS OF DATA ON DISC
865   REAL Nscans                         ! NUMBER OF SCANS ON DISC
870   REAL Scan_rate                      ! SCAN RATE/SCEOND FROM DISC
875   REAL Int_data                       ! INTERRUPT DATA - WHICH CHANNEL
880   REAL Int_pointer                    ! INTERRUPT POINTER - WHERE IN DATA
885   INTEGER Signals(35,7000) BUFFER     ! CALCULATED DATA MATRIX
890   ALLOCATE REAL Scale_factor(1:Total_channels)   ! SCALE FACTOR FOR CALCULA
                                          TED DATA MATRIX 'Signals' ABOVE
895   REAL A(6,3)                         ! THE CURRENT 'A' MATRIX IN USE
900   REAL A_matrix(6,3,6)                ! ALL OF THE 'A' MATRIX USED IN CONVERT
                                        ING THE STRAIN GUAGE READINGS TO FORCES
905   REAL Mean(2,6)                      ! MIDPOINTS FOR HYDRO-DYNAMIC
                                          CORRECTION
910   DIM Title$[80]                      ! TITLE READ FROM DATA DISC
915   DIM Dates$[12]                      ! DATE READ FROM DATA DISC
920   DIM Times$[12]                      ! TIME READ FROM DATA DISC
925   ALLOCATE Units$(Total_channels)[6]         !UNITS OF ENGINEERING CONVERTED
                                                  AQUIRED CHANNELS
930   ALLOCATE REAL Pre_filter(-50:50)   ! CALCULATED PRE-FILTER COEFFICIENTS
935   ALLOCATE REAL Post_filter(-50:50)  ! CALCULATED POST-FILTER COEFFICIENTS
940   INTEGER Filter_size                 ! SIZE OF CURRENT FILTER BEING USED
945   REAL Ripple                         ! RIPPLE dB FOR FILTER DESIGN
950   REAL Rejection                      ! REJECTION d3 FOR FILTER DESIGN
955   REAL Upper_limit                    ! UPPER LIMIT OF FREQUENCY FOR FILTER
                                          DESIGN
```

```
960    REAL Lower_limit                      ! LOWER LIMIT OF FREQUENCY FOR FILTER
                                               DESIGN
965    REAL Because                          ! WHO KNOWS?
970      !
975      !DATA FILES FOR EVENT DATA(DURATION OF EVENT,BLADE ORIEN.,TORQUE AREA)
980    REAL Dur_event(350)
985    REAL Blade_orien_p(350)
990    REAL Blade_orien_s(350)
995    REAL Blade_orien_e(350)
1000   REAL Energy_torque(350)
1005     !
1010     !DATA FILES FOR EVENT DATA ( RADIAL AND TANGENTIAL LOCATION )
1015   REAL Av_rad_loc(350)
1020   REAL Av_circ_loc(350)
1025   REAL Peak_rad_loc                     ! STORED WITH BATCH MODE
1030   REAL Peak_circ_loc
1035   !
1040   INTEGER Angle_11,Angle_12,Angle_13,Angle_14
1045                                         ! DISPLACEMENT TRANSDUCER ANGLES
1050   INTEGER Shuffle1(1:12)                ! TEMP. SHUFFLE MATRIX FOR FFT
1055   INTEGER One_channel                   ! FLAG FOR Find_min_max ROUTINE
1060   INTEGER I,J,R,Q,Nn,S,L,Mm             ! MISC. VARIABLES FOR FFT
1065   REAL Temp1,R1,R2,Inverse              ! MISC. VARIABLES FOR FFT
1070   INTEGER First_tape_read
1075   REAL Prop_data(1:3)
1080   REAL Times(1:3)
1085  !
1090   Batch_mode=0                          ! DEFAULT IS REGULAR MODE
1095   Rpm_channel=15                        ! CHANNEL NUMBER OF THE SHAFT SENSOR
1100   Angle_11=15                           ! ANGLE OF AFT PORT DISPLACEMENT PROBE
1105   Angle_12=285                          ! ANGLE OF AFT TOP DISPLACEMENT PROBE
1110   Angle_13=315                          ! ANGLE OF FWD PORT DISPLACEMENT PROBE
1115   Angle_14=225                          ! ANGLE OF FWD STBD DISPLACEMENT PROBE
1120   DIM Num$[2]                           ! STRING IN CHAN. DES.
1125   I$=CHR$(129)                          ! INVERSE VIDEO ON
1130   N$=CHR$(128)                          ! INVERSE VIDEO OFF
1135   REAL Min_value(34)                    ! MIN VALUE OF EACH CHANNEL
1140   REAL Max_value(34)                    ! MAX VALUE OF EACH CHANNEL
1145   REAL Mean_value(34)                   ! MEAN VALUE OF EACH CHANNEL
1150   !
1155   First_event_pl=1   .                  ! FLAG FOR PLOTTING IN BATCH MODE
1160   Main_exit=0                           ! FLAG TO STAY IN MAIN PART OF PROGRAM
1165   Channel_x=2                           ! DEFAULT X_AXIS CHANNEL WHEN NOT
                                               VERSES TIME
1170   Channel_y=1                           ! DEFAULT Y-AXIS CHANNEL FIRST PLOTTED
1175   Time_plot=1                           ! DEFAULT PLOT OF CHANNELS VERSES TIME
1180   First_tape_read=1                     ! DEFAULT FOR READ_MAG_TAPE ROUTINE
1185   DIM New_counter$[5]                   ! Y_AXIS LABEL COUNTER
1190   INTEGER Screen_buffer(12480)
1195   !
1200   INTEGER E_st                          ! START POINT FOR EVENTS
1205   INTEGER E_pk                          ! PEAK POINT FOR EVENTS
1210   INTEGER E_end                         ! END POINT FOR EVENTS
1215   REAL Nice_scale(0:14)                 !"NICE" SCALE VALUES
1220   DATA 0,1.0,1.25,1.5,1.75,2.0,2.5,3,4,5,6,7,8,9,10
1225   READ Nice_scale(*)
1230     !
1235   Neg_ch16_cor=.0143/.0175              ! SCALE CORRECTION FOR PROP PITCH
1240     !
1245     !DATA FILES FOR EVENT DATA(DURATION OF EVENT,BLADE ORIEN.,TORQUE AREA)
1250   MAT Dur_event= (-1.E+6)
1255   MAT Blade_orien_p= (-1.E+6)
1260   MAT Blade_orien_s= (-1.E+6)
1265   MAT Blade_orien_e= (-1.E+6)
1270   MAT Energy_torque= (-1.E+6)
1275     !
```

```
1280      !DATA FILES FOR EVENT DATA ( RADIAL AND TANGENTIAL LOCATION )
1285   MAT Av_rad_loc= (-1.E+6)
1290   MAT Av_circ_loc= (-1.E+6)
1295  !
1300  !                        MAINLINE PROCESSING
1305  !
1310 Top: !
1315   Same_data=0                       ! CHECKS IF THE TEST DATA IS NEW
1320   One_channel=0                     ! Find_min_max ROUTINE CALCULATES ALL
1325                                     ! CHANNELS
1330   Channels=18                      ! NUMBER OF DATA CHANNELS READ FROM DISC
1335   Nscans=7000                       ! NUMBER OF DATA POINTS PER CHANNEL
1340   Position_flag=0                   ! FOR CALCULATION OF PROBE POSITIONS
1345   MAT Signals= (0)
1350   MAT A= (0)
1355   MAT A_matrix= (0)
1360   MAT Mean= (0)
1365   MAT Prop_data= (0)
1370   MAT Min_value= (-1.E+6)
1375   MAT Max_value= (-1.E+6)
1380   MAT Mean_value= (-1.E+6)
1385   MAT Screen_buffer= (0)
1390   MAT Rpm= (0)
1395   MAT Rpm_pulse= (0)
1400   !
1405   Time_loc_start=-1.E+6
1410   Time_loc_peak=-1.E+6
1415   Time_loc_end=-1.E+6
1420   Start_loc_th=-1.E+6
1425   Peak_loc_th=-1.E+6
1430   End_loc_th=-1.E+6
1435   Start_loc_tq=-1.E+6
1440   Peak_loc_tq=-1.E+6
1445   End_loc_tq=-1.E+6
1450   !
1455   Time_tq_start=-1.E+6
1460   Time_tq_peak=-1.E+6
1465   Time_tq_end=-1.E+6
1470   Start_tq_thrust=-1.E+6
1475   Peak_tq_thrust=-1.E+6
1480   End_tq_thrust=-1.E+6
1485   Start_tq_torque=-1.E+6
1490   Peak_tq_torque=-1.E+6
1495   End_tq_torque=-1.E+6
1500   !
1505   Time_th_start=-1.E+6
1510   Time_th_peak=-1.E+6
1515   Time_th_end=-1.E+6
1520   Start_th_thrust=-1.E+6
1525   Peak_th_thrust=-1.E+6
1530   End_th_thrust=-1.E+6
1535   Start_th_torque=-1.E+6
1540   Peak_th_torque=-1.E+6
1545   End_th_torque=-1.E+6
1550   !
1555   IF Batch_mode THEN GOTO Batchmode
1560   Hard_copy=0
1565   PRINTER IS 1
1570   PRINT CHR$(12)
1575   Today$=DATE$(TIMEDATE)
1580   IF Today$[8,11]="1900" THEN GOSUB Set_time
1585   GOSUB Start_inst
1590   GOSUB Mainline
1595   GRAPHICS OFF
1600   GCLEAR
1605   Hard_copy=0
```

```
1610   PRINTER IS 1
1615   STOP
1620  !
1625  ! ============================================================
1630  !  MAINLINE
1635  ! ============================================================
1640 Mainline:    !
1645   Mainline_exit=0
1650   OFF KEY
1655   ON KEY 0 LABEL "TEST CHAN LIST" GOSUB Test_chan_list
1660   ON KEY 1 LABEL "CALB CHAN LIST" GOSUB Calb_chan_list
1665   ON KEY 2 LABEL "RED TEST/BATCH" GOSUB Read_data
1670   ON KEY 12 GOTO Start_dk_batch
1675   ON KEY 3 LABEL "READ CALB.DATA" GOSUB Read_calib_data
1680   ON KEY 4 LABEL "RED TAPE/BATCH" GOSUB Read_mag_tape
1685   ON KEY 14 GOTO Start_batchmode
1690   ON KEY 5 LABEL "INSTRUCTIONS/A" GOSUB Instructions
1695   ON KEY 15 GOSUB Start_inst
1700   ON KEY 6 LABEL "PLOT HELP" GOSUB Qk
1705   ON KEY 7 LABEL "HELP DISC DATA" GOSUB Dk
1710   ON KEY 8 LABEL "HELP CURSOR" GOSUB Cur
1715   ON KEY 9 LABEL "HELP TAPE DATA" GOSUB Mg_tp
1720 Mainline_idle:IF NOT Mainline_exit THEN Mainline_idle
1725   PRINT CHR$(12)
1730   OFF KEY
1735   Plot_start_time=0                   ! DEFAULT START TIME FOR X-Y PLOTTING
1740   Plot_end_time=Nscans/Scan_rate      ! DEFAULT END TIME FOR X-Y PLOTTING
1745   Xmin=0                              ! DEFAULT START TIME FOR TIME PLOTS
1750   Xmax=7000                           ! DEFAULT END TIME FOR TIME PLOTS
1755   GOSUB Rpm_calculate
1760   Disp_int=1
1765   GOTO Quick_look
1770   !
1775  ! ====================================================================
1780  ! START DK BATCH
1785  ! ====================================================================
1790 Start_dk_batch: !
1795   OFF KEY
1800   OFF KNOB
1805   PRINT CHR$(12)
1810   Batch_mode=1
1815   Tape_mode=0
1820   ! Hard_copy=1
1825   ! PRINTER IS 701
1830   Time_plot=0
1835   GOTO Top
1840   !
1845  ! ====================================================================
1850  ! START BATCHMODE
1855  ! ====================================================================
1860 Start_batchmode: !
1865   OFF KEY
1870   OFF KNOB
1875   PRINT CHR$(12)
1880   Batch_mode=1
1885   Tape_mode=1
1890   ! Hard_copy=1
1895   ! PRINTER IS 701
1900   Time_plot=0
1905   GOTO Top
1910   !
1915  ! ====================================================================
1920  ! BATCHMODE
1925  ! ====================================================================
1930 Batchmode:  !
1935   IF Tape_mode THEN
```

```
1940      GOSUB Read_mag_tape
1945   ELSE
1950      GOSUB Read_data
1955   END IF
1960   IF Same_data THEN GOTO New_disk
1965   IF End_of_data THEN GOTO The_end
1970   GOSUB Rpm_calculate
1975   Xmin=0                            ! DEFAULT START TIME FOR TIME PLOTS
1980   Xmax=7000                         ! DEFAULT END TIME FOR TIME PLOTS
1985   Plot_start_time=0                 ! DEFAULT START TIME FOR X-Y PLOTTING
1990   Plot_end_time=Nscans/Scan_rate    ! DEFAULT END TIME FOR X-Y PLOTTING
1995   GOSUB Calculate
2000   IF Same_data THEN GOTO New_disk
2005   Start_point=1                     ! LOWER LIMIT OF GOOD DATA FOR MIN_MAX
2010   Finish_point=Nscans               ! UPPER LIMIT OF GOOD DATA FOR MIN_MAX
2015   GOSUB Find_min_max
2020   GOSUB Find_load_loc
2025   IF Mean_value(8)<>0 AND Mean_value(9)<>0 THEN
2030      GOSUB Find_th_event
2035      GOSUB Find_tq_event
2040   ELSE
2045      PRINT
2050      PRINT "NOT ABLE TO FIND TORQUE AND THRUST EVENTS FOR TEST #";Test_numb
er
2055   END IF
2060   GOSUB Save_to_disc
2065   GOTO New_disk
2070   !
2075  ! ==================================================================
2080  ! FIND LOAD LOC
2085  ! ==================================================================
2090 Find_load_loc: !
2095   E_pk=1
2100   DISP "FINDING PEAK_RAD_LOC and PEAK_CIRC_LOC"
2105   IF ABS(Max_value(21))>ABS(Min_value(21)) THEN
2110      Force_dir=1
2115      WHILE (Signals(21,E_pk)/Scale_factor(21)*Slope(21)+Offset(21)<>Max_val
ue(21)) AND E_pk<Nscans
2120         E_pk=E_pk+1
2125      END WHILE
2130   ELSE
2135      Force_dir=-1
2140      WHILE (Signals(21,E_pk)/Scale_factor(21)*Slope(21)+Offset(21)<>Min_val
ue(21)) AND E_pk<Nscans
2145         E_pk=E_pk+1
2150      END WHILE
2155   END IF
2160   IF E_pk=Nscans THEN
2165      PRINT
2170      PRINT "MATCH NOT FOUND FOR PEAK FORCE FOR TEST #";Test_number
2175   ELSE
2180      Time_loc_peak=E_pk/Scan_rate
2185      Peak_loc_th=Signals(8,E_pk)/Scale_factor(8)*Slope(8)+Offset(8)
2190      Peak_loc_tq=Signals(9,E_pk)/Scale_factor(9)*Slope(9)+Offset(9)
2195      Peak_rad_loc=Signals(22,E_pk)/Scale_factor(22)*Slope(22)+Offset(22)
2200      Peak_circ_loc=Signals(23,E_pk)/Scale_factor(23)*Slope(23)+Offset(23)
2205      GOSUB Find_loc_start
2210      GOSUB Find_loc_end
2215      IF Time_loc_start<>-1.E+6 AND Time_loc_end<>-1.E+6 THEN
2220         Start_point=E_st
2225         Finish_point=E_end
2230         Channel_x=8
2235         Channel_y=9
2240         GOSUB Ch_min_max
2245         Av_loc_th=Mean_channel_x
2250         Av_loc_tq=Mean_channel_y
```

```
2255          Channel_y=21
2260          GOSUB Ch_min_max
2265          Av_loc_force=Mean_channel_y
2270          Force_area=ABS(Av_loc_force-Mean_value(21))*(E_end-E_st)/Scan_rate
2275       END IF
2280       PRINT
2285       PRINT "TEST #";Test_number;"    BLADE FORCE EVENT"
2290       PRINT
2295       PRINT "PEAK RAD","PEAK CIRC","FORCE","AVERAGE","AVERAGE","FORCE"
2300       PRINT "LOCATION","LOCATION","DIRECTION","THRUST","TORQUE","AREA"
2305       PRINT Peak_rad_loc,Peak_circ_loc,Force_dir,Av_loc_th,Av_loc_tq,Force_a
rea
2310       PRINT
2315       PRINT "SIGNAL","START","PEAK","END"
2320       PRINT "TIME",Time_loc_start,Time_loc_peak,Time_loc_end
2325       PRINT "THRUST",Start_loc_th,Peak_loc_th,End_loc_th
2330       PRINT "TORQUE",Start_loc_tq,Peak_loc_tq,End_loc_tq
2335       Min_value(11)=Peak_rad_loc
2340       Max_value(11)=Peak_circ_loc
2345       Mean_value(11)=Force_dir
2350       Mean_value(24)=Force_area
2355    END IF
2360    RETURN
2365    !
2370    ! ====================================================================
2375    ! FIND LOC START
2380    ! ====================================================================
2385 Find_loc_start: !
2390    E_st=E_pk
2395    IF Force_dir=1 THEN
2400       WHILE (Signals(21,E_st)/Scale_factor(21)*Slope(21)+Offset(21)>Mean_val
ue(21)) AND E_st>1
2405          E_st=E_st-1
2410       END WHILE
2415    ELSE
2420       WHILE (Signals(21,E_st)/Scale_factor(21)*Slope(21)+Offset(21)<Mean_val
ue(21)) AND E_st>1
2425          E_st=E_st-1
2430       END WHILE
2435    END IF
2440    IF E_st=1 THEN
2445       PRINT
2450       PRINT "START OF BLADE FORCE EVENT OCCURS BEFORE RECORDING"
2455    ELSE
2460       Time_loc_start=E_st/Scan_rate
2465       Start_loc_th=Signals(8,E_st)/Scale_factor(8)*Slope(8)+Offset(8)
2470       Start_loc_tq=Signals(9,E_st)/Scale_factor(9)*Slope(9)+Offset(9)
2475    END IF
2480    RETURN
2485       !
2490    ! ====================================================================
2495    ! FIND LOC END
2500    ! ====================================================================
2505 Find_loc_end: !
2510    E_end=E_pk
2515    IF Force_dir=1 THEN
2520       WHILE (Signals(21,E_end)/Scale_factor(21)*Slope(21)+Offset(21)>Mean_va
lue(21)) AND E_end<Nscans
2525          E_end=E_end+1
2530       END WHILE
2535    ELSE
2540       WHILE (Signals(21,E_end)/Scale_factor(21)*Slope(21)+Offset(21)<Mean_va
lue(21)) AND E_end<Nscans
2545          E_end=E_end+1
2550       END WHILE
2555    END IF
```

```
2560   IF E_end=Nscans THEN
2565      PRINT
2570      PRINT "END OF BLADE FORCE EVENT OCCURS AFTER RECORDING"
2575   ELSE
2580      Time_loc_end=E_end/Scan_rate
2585      End_loc_th=Signals(8,E_end)/Scale_factor(8)*Slope(8)+Offset(8)
2590      End_loc_tq=Signals(9,E_end)/Scale_factor(9)*Slope(9)+Offset(9)
2595   END IF
2600   RETURN
2605   !
2610   ! ======================================================================
2615   ! FIND TH EVENT
2620   ! ======================================================================
2625 Find_th_event: !
2630    E_pk=1
2635    DISP "FINDING THRUST EVENT"
2640    IF Max_value(8)>(250+Min_value(8)) AND ABS(Mean_value(8))>250 THEN
2645       IF ABS(Max_value(8)-Mean_value(8))>ABS(Mean_value(8)-Min_value(8)) THE
N
2650          Check_max=1
2655          WHILE (Signals(8,E_pk)/Scale_factor(8)*Slope(8)+Offset(8)<>Max_valu
e(8)) AND E_pk<Nscans
2660             E_pk=E_pk+1
2665          END WHILE
2670       ELSE
2675          Check_max=0
2680          WHILE (Signals(8,E_pk)/Scale_factor(8)*Slope(8)+Offset(8)<>Min_valu
e(8)) AND E_pk<Nscans
2685             E_pk=E_pk+1
2690          END WHILE
2695       END IF
2700    ELSE
2705       PRINT
2710       PRINT "NO THRUST EVENT FOR TEST #";Test_number
2715       RETURN
2720    END IF
2725    IF E_pk=Nscans THEN
2730       PRINT
2735       PRINT "MATCH NOT FOUND FOR PEAK THRUST FOR TEST #";Test_number
2740       RETURN
2745    END IF
2750    Time_th_peak=E_pk/Scan_rate
2755    Peak_th_thrust=Signals(8,E_pk)/Scale_factor(8)*Slope(8)+Offset(8)
2760    Peak_th_torque=Signals(9,E_pk)/Scale_factor(9)*Slope(9)+Offset(9)
2765    GOSUB Find_th_start
2770    GOSUB Find_th_end
2775    IF Time_th_start<>-1.E+6 AND Time_th_end<>-1.E+6 THEN PRINT CHR$(12)
2780    PRINT
2785    PRINT "TEST #";Test_number;"    THRUST EVENT"
2790    PRINT
2795    PRINT "SIGNAL","START","PEAK","END"
2800    PRINT "TIME",Time_th_start,Time_th_peak,Time_th_end
2805    PRINT "THRUST",Start_th_thrust,Peak_th_thrust,End_th_thrust
2810    PRINT "TORQUE",Start_th_torque,Peak_th_torque,End_th_torque
2815    !  IF Time_th_start<>-1.E+6 AND Time_th_end<>-1.E+6 THEN GOSUB Plot_th_ev
ent      PLOTS EVENT
2820    Min_value(25)=Time_th_start
2825    Max_value(25)=Time_th_peak
2830    Mean_value(25)=Time_th_end
2835    Min_value(26)=Start_th_thrust
2840    Max_value(26)=Peak_th_thrust
2845    Mean_value(26)=End_th_thrust
2850    Min_value(27)=Start_th_torque
2855    Max_value(27)=Peak_th_torque
2860    Mean_value(27)=End_th_torque
2865    RETURN
```

```
2870      !
2875   ! ====================================================================
2880   ! FIND TH START
2885   ! ====================================================================
2890 Find_th_start: !
2895    E_st=E_pk
2900    IF Check_max THEN
2905       WHILE (Signals(8,E_st)/Scale_factor(8)*Slope(8)+Offset(8)>Mean_value(8
)) AND E_st>1
2910           E_st=E_st-1
2915       END WHILE
2920    ELSE
2925       WHILE (Signals(8,E_st)/Scale_factor(8)*Slope(8)+Offset(8)<Mean_value(8
)) AND E_st>1
2930           E_st=E_st-1
2935       END WHILE
2940    END IF
2945    IF E_st=1 THEN
2950       PRINT
2955       PRINT "START OF THRUST EVENT OCCURS BEFORE RECORDING"
2960    ELSE
2965       Time_th_start=E_st/Scan_rate
2970       Start_th_thrust=Signals(8,E_st)/Scale_factor(8)*Slope(8)+Offset(8)
2975       Start_th_torque=Signals(9,E_st)/Scale_factor(9)*Slope(9)+Offset(9)
2980    END IF
2985    RETURN
2990       !
2995   ! ====================================================================
3000   ! FIND TH END
3005   ! ====================================================================
3010 Find_th_end: !
3015    E_end=E_pk
3020    IF Check_max THEN
3025       WHILE (Signals(8,E_end)/Scale_factor(8)*Slope(8)+Offset(8)>Mean_value(
8)) AND E_end<Nscans
3030           E_end=E_end+1
3035       END WHILE
3040    ELSE
3045       WHILE (Signals(8,E_end)/Scale_factor(8)*Slope(8)+Offset(8)<Mean_value(
8)) AND E_end<Nscans
3050           E_end=E_end+1
3055       END WHILE
3060    END IF
3065    IF E_end=Nscans THEN
3070       PRINT
3075       PRINT "END OF THRUST EVENT OCCURS AFTER RECORDING"
3080    ELSE
3085       Time_th_end=E_end/Scan_rate
3090       End_th_thrust=Signals(8,E_end)/Scale_factor(8)*Slope(8)+Offset(8)
3095       End_th_torque=Signals(9,E_end)/Scale_factor(9)*Slope(9)+Offset(9)
3100    END IF
3105    RETURN
3110    !
3115   ! ====================================================================
3120   ! FIND TQ EVENT
3125   ! ====================================================================
3130 Find_tq_event: !
3135    E_pk=1
3140    DISP "FINDING TORQUE EVENT"
3145    IF Max_value(9)>1.25*Mean_value(9) AND Mean_value(9)>100 THEN
3150       WHILE (Signals(9,E_pk)/Scale_factor(9)*Slope(9)+Offset(9)<>Max_value(9
)) AND E_pk<Nscans
3155           E_pk=E_pk+1
3160       END WHILE
3165    ELSE
3170       PRINT
```

```
3175      PRINT "NO TORQUE EVENT FOR TEST #";Test_number
3180      RETURN
3185   END IF
3190   IF E_pk=Nscans THEN
3195      PRINT
3200      PRINT "MATCH NOT FOUND FOR PEAK TORQUE FOR TEST #";Test_number
3205      RETURN
3210   END IF
3215   Time_tq_peak=E_pk/Scan_rate
3220   Peak_tq_thrust=Signals(8,E_pk)/Scale_factor(8)*Slope(8)+Offset(8)
3225   Peak_tq_torque=Signals(9,E_pk)/Scale_factor(9)*Slope(9)+Offset(9)
3230   GOSUB Find_tq_start
3235   GOSUB Find_tq_end
3240   IF Time_tq_start<>-1.E+6 AND Time_tq_end<>-1.E+6 THEN PRINT CHR$(12)
3245   PRINT
3250   PRINT "TEST #";Test_number;"     TORQUE EVENT"
3255   PRINT
3260   PRINT "SIGNAL","START","PEAK","END"
3265   PRINT "TIME",Time_tq_start,Time_tq_peak,Time_tq_end
3270   PRINT "THRUST",Start_tq_thrust,Peak_tq_thrust,End_tq_thrust
3275   PRINT "TORQUE",Start_tq_torque,Peak_tq_torque,End_tq_torque
3280   ! IF Time_tq_start<>-1.E+6 AND Time_tq_end<>-1.E+6 THEN GOSUB Plot_tq_eve
nt     PLOTS EVENT
3285   Min_value(28)=Time_tq_start
3290   Max_value(28)=Time_tq_peak
3295   Mean_value(28)=Time_tq_end
3300   Min_value(29)=Start_tq_thrust
3305   Max_value(29)=Peak_tq_thrust
3310   Mean_value(29)=End_tq_thrust
3315   Min_value(30)=Start_tq_torque
3320   Max_value(30)=Peak_tq_torque
3325   Mean_value(30)=End_tq_torque
3330   RETURN
3335      !
3340  ! ======================================================================
3345  ! FIND TQ START
3350  ! ======================================================================
3355 Find_tq_start: !
3360    E_st=E_pk
3365    WHILE (Signals(9,E_st)/Scale_factor(9)*Slope(9)+Offset(9)>Mean_value(9))
AND E_st>1
3370       E_st=E_st-1
3375    END WHILE
3380    IF E_st=1 THEN
3385       PRINT
3390       PRINT "START OF TORQUE EVENT OCCURS BEFORE RECORDING"
3395    ELSE
3400       Time_tq_start=E_st/Scan_rate
3405       Start_tq_thrust=Signals(8,E_st)/Scale_factor(8)*Slope(8)+Offset(8)
3410       Start_tq_torque=Signals(9,E_st)/Scale_factor(9)*Slope(9)+Offset(9)
3415    END IF
3420    RETURN
3425       !
3430  ! ======================================================================
3435  ! FIND TQ END
3440  ! ======================================================================
3445 Find_tq_end: !
3450    E_end=E_pk
3455    WHILE (Signals(9,E_end)/Scale_factor(9)*Slope(9)+Offset(9)>Mean_value(9))
 AND E_end<Nscans
3460       E_end=E_end+1
3465    END WHILE
3470    IF E_end=Nscans THEN
3475       PRINT
3480       PRINT "END OF TORQUE EVENT OCCURS AFTER THE END OF RECORDING"
3485    ELSE
```

```
3490       Time_tq_end=E_end/Scan_rate
3495       End_tq_thrust=Signals(8,E_end)/Scale_factor(8)*Slope(8)+Offset(8)
3500       End_tq_torque=Signals(9,E_end)/Scale_factor(9)*Slope(9)+Offset(9)
3505    END IF
3510    RETURN
3515       !
3520   ! ==============================================================================
3525   ! PLOT TH EVENT
3530   ! ==============================================================================
3535 Plot_th_event: !
3540    GOSUB Channel_disp
3545    IF First_event_pl THEN
3550       GOSUB Quick_look
3555       First_event_pl=0
3560    END IF
3565    Channel_x=8
3570    Channel_y=9
3575    GOSUB Channel_disp
3580    Start_point=E_st
3585    Finish_point=E_end
3590    GOSUB Ch_min_max
3595    Xmin=Min_channel_x
3600    Xmax=Max_channel_x
3605    Ymin=Min_channel_y
3610    Ymax=Max_channel_y
3615    Plot_start_time=Time_th_start
3620    Plot_end_time=Time_th_end
3625    GOSUB New_plot
3630    GOSUB Dump_graphics
3635    RETURN
3640       !
3645   ! ==============================================================================
3650   ! PLOT TQ EVENT
3655   ! ==============================================================================
3660 Plot_tq_event: !
3665    GOSUB Channel_disp
3670    IF First_event_pl THEN
3675       GOSUB Quick_look
3680       First_event_pl=0
3685    END IF
3690    Channel_x=8
3695    Channel_y=9
3700    GOSUB Channel_disp
3705    Start_point=E_st
3710    Finish_point=E_end
3715    GOSUB Ch_min_max
3720    Xmin=Min_channel_x
3725    Xmax=Max_channel_x
3730    Ymin=Min_channel_y
3735    Ymax=Max_channel_y
3740    Plot_start_time=Time_tq_start
3745    Plot_end_time=Time_tq_end
3750    GOSUB New_plot
3755    GOSUB Dump_graphics
3760    RETURN
3765       !
3770   !
3775   ! ====================================================================
3780   !    FIND MIN, MAX AND MEAN OF DATA BETWEEN SPECIFIED TIMES
3785   ! ====================================================================
3790 Ch_min_max:     !
3795    Points_span=Finish_point-Start_point+1
3800    !
3805    Max_channel_y=-32767
3810    Min_channel_y=32767
3815    Mean_channel_y=0
```

```
3820   FOR I=Start_point TO Finish_point
3825      Min_channel_y=MIN(Min_channel_y,Signals(Channel_y,I))
3830      Max_channel_y=MAX(Max_channel_y,Signals(Channel_y,I))
3835      Mean_channel_y=Mean_channel_y+Signals(Channel_y,I)
3840   NEXT I
3845   Mean_channel_y=(Mean_channel_y/Scale_factor(Channel_y))/Points_span*Slope
(Channel_y)+Offset(Channel_y)
3850   Min_channel_y=(Min_channel_y/Scale_factor(Channel_y))*Slope(Channel_y)+Of
fset(Channel_y)
3855   Max_channel_y=(Max_channel_y/Scale_factor(Channel_y))*Slope(Channel_y)+Of
fset(Channel_y)
3860   IF Min_channel_y>Max_channel_y THEN
3865      Temp_val=Max_channel_y
3870      Max_channel_y=Min_channel_y
3875      Min_channel_y=Temp_val
3880   END IF
3885   IF NOT Time_plot THEN
3890      Max_channel_x=-32767
3895      Min_channel_x=32767
3900      Mean_channel_x=0
3905      FOR I=Start_point TO Finish_point
3910         Min_channel_x=MIN(Min_channel_x,Signals(Channel_x,I))
3915         Max_channel_x=MAX(Max_channel_x,Signals(Channel_x,I))
3920         Mean_channel_x=Mean_channel_x+Signals(Channel_x,I)
3925      NEXT I
3930      Mean_channel_x=(Mean_channel_x/Scale_factor(Channel_x))/Points_span*Sl
ope(Channel_x)+Offset(Channel_x)
3935      Min_channel_x=(Min_channel_x/Scale_factor(Channel_x))*Slope(Channel_x)
+Offset(Channel_x)
3940      Max_channel_x=(Max_channel_x/Scale_factor(Channel_x))*Slope(Channel_x)
+Offset(Channel_x)
3945      IF Min_channel_x>Max_channel_x THEN
3950         Temp_val=Max_channel_x
3955         Max_channel_x=Min_channel_x
3960         Min_channel_x=Temp_val
3965      END IF
3970   END IF
3975   RETURN
3980      !
3985   ! ===================================================================
3990   ! DUMP GRAPHICS
3995   ! ===================================================================
4000 Dump_graphics: !
4005   DUMP DEVICE IS 701
4010   DUMP GRAPHICS
4015   RETURN
4020   !
4025   ! ===================================================================
4030   ! MAIN LOOP
4035   ! ===================================================================
4040 Main_loop:      !
4045   IF Disp_int THEN
4050      DISP "INTERRUPT DATA = ";Int_data;" INTERRUPT POINTER = ";Int_pointer
4055      Disp_int=0
4060   END IF
4065   GOSUB Main_keys
4070   ON KNOB .1,9 GOSUB Move_cursor
4075 Main_sub_loop:    !
4080   IF NOT Main_exit THEN Main_sub_loop
4085   GCLEAR
4090   GRAPHICS OFF
4095   RETURN
4100   !
4105   ! ===================================================================
4110   ! STARTING INSTRUTIONS
4115   ! ===================================================================
```

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **"ANALYZE 4 - 1"**

APPENDIX A

```
4120 Start_inst:!
4125   Hard_copy=0
4130   PRINTER IS 1
4135   PRINT CHR$(12)
4140   PRINT "YOU ARE IN THE 'INFORMATION' MODE. THIS MODE CAN ONLY BE ACCESSED"
4145   PRINT "WHEN THE PROGRAM IS FIRST RUN. INFORMATION MAY BE OBTAINED BY"
4150   PRINT "PRESSING ANY OF THE LABLED SOFT KEYS EXCEPT THE FOLLOWING:"
4155   PRINT "'READ TEST DATA', 'READ CALIB DATA', or; 'READ TAPE DATA'."
4160   PRINT "THESE FUNCTION KEYS WILL READ DATA FROM A TAPE OR DISK, AS"
4165   PRINT "REQUIRED, AND WILL PLACE YOU IN THE MAIN PROGRAM."
4170   PRINT "A GOOD PLACE TO START IS WITH THE 'INFORMATION' SOFT KEY."
4175   PRINT "YOU MAY GET ANOTHER LISTING OF THIS TEXT BY PRESSING THE 'SHIFT'"
4180   PRINT "KEY AND THE 'INSTRUCTIONS' KEY AT THE SAME TIME. TO ENTER THE"
4185   PRINT "'HELP' MODE FROM THE MAIN PROGRAM, PRESS THE 'HELP' SOFT KEY."
4190   PRINT "THE KEYS WHICH THEN APPEAR, WILL PROVIDE HELP FOR THE TOPICS"
4195   PRINT "LISTED. TO RETURN TO THE MAIN PROGRAM FROM THE 'HELP' ROUTINE,"
4200   PRINT "PRESS THE 'EXIT' CHOICE."
4205   RETURN
4210  !
4215  ! ======================================================================
4220  ! INSTRUTIONS
4225  ! ======================================================================
4230 Instructions:!
4235   Hard_copy=0
4240   PRINTER IS 1
4245   PRINT CHR$(12)
4250   PRINT "THE FIRST CHOICE GIVEN ON A SOFT KEY IS CHOOSEN USING JUST THE"
4255   PRINT "SOFT KEY, THE SECOND CHOICE IS OBTAINED BY HOLDING DOWN THE"
4260   PRINT "'SHIFT' KEY WHILE PRESSING THE SOFT KEY."
4265   PRINT "IN ORDER TO CHOOSE THE DEFAULT VALUE OR LAST VALUE USED FOR"
4270   PRINT "ANY INPUT, PRESS THE 'CONTINUE' KEY WHEN ASKED FOR INPUT."
4275   PRINT "THIS PROGRAM IS USED FOR VIEWING THE 343 EVENT DISKS RECORDED ON"
4280   PRINT "BOARD THE M.V. ROBERT LEMEUR DURING JUNE-JULY 1984 AND THE 20"
4285   PRINT "DYNAMIC CALIBRATION DISKS RECORDED ON THE WURMLINGER DURING MAY"
4290   PRINT "1984. DATA CAN BE DISPLAYED VERSES TIME OR CHANNEL VERSES CHANNEL"
4295   PRINT "THE DATA CAN BE PROCESSED IN THE MAJOR FOLLOWING WAYS:"
4300   PRINT "CALCULATE BLADE FORCES"
4305   PRINT "PERFORM FAST FOURIER TRANSFORMS"
4310   PRINT "DIGITALLY FILTER RECORDED DATA"
4315   PRINT "A HARD COPY OF THE GRAPH ON THE CRT MAY BE OBTAINED BY USING THE"
4320   PRINT "'DUMP GRAPHICS' KEY BUILT INTO THE COMPUTER"
4325   PRINT "NOTE: THE SHAFT REFERENE PULSE CH.15 CORRESPONDS TO THE CENTER OF"
4330   PRINT "THE INSTRUMENTED BLADE AT 10 O'CLOCK, LOOKING FORWARD. SHAFT"
4335   PRINT "ROTATES INBOARD AT THE TOP. BLADE SUBTENDS AN ANGLE OF APP.60 DEG"
4340   RETURN
4345   !
4350   ! ======================================================================
4355   ! RECORDED_CH_DES
4360   ! ======================================================================
4365 Recorded_ch_des:  !
4370   IF Calib_data THEN
4375     !
4380     ! CHANNEL DESCRIPTION FOR WURMLINGER CALIBRATION TEST AQUIRED CHANNELS
4385     !
4390      Channel_desc$(1)="CENTRE BENDING"
4395      Channel_desc$(2)="TRAILING EDGE TORQUE"
4400      Channel_desc$(3)="LEADING EDGE BENDING"
4405      Channel_desc$(4)="CENTRE TORQUE"
4410      Channel_desc$(5)="TRAILING EDGE BENDING"
4415      Channel_desc$(6)="LEADING EDGE TORQUE"
4420      Channel_desc$(7)="SLIDING BLOCK FORCE"
4425      Channel_desc$(8)="LOAD CELL FORCE"
4430      Channel_desc$(9)="BLANK CHANNEL"
4435      Channel_desc$(10)="BLANK CHANNEL"
4440      Channel_desc$(11)="CENTRE BENDING"
4445      Channel_desc$(12)="TRAILING EDGE TORQUE"
```

```
4450        Channel_desc$(13)="LEADING EDGE BENDING"
4455        Channel_desc$(14)="CENTRE TORQUE"
4460        Channel_desc$(15)="TRAILING EDGE BENDING"
4465        Channel_desc$(16)="LEADING EDGE TORQUE"
4470        Channel_desc$(17)="SLIDING BLOCK FORCE"
4475        Channel_desc$(18)="LOAD CELL FORCE"
4480        !
4485 Data_for_calib:!
4490        DATA .0452,.0123,.0452,.0123,.0452,.0123,.611,-0.0366,1,1
4495        DATA .0452,.0123,.0452,.0123,.0452,.0123,.611,-0.0366
4500        DATA 1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1
4505        RESTORE Data_for_calib
4510        READ Slope(*)! TO CONVERT WURMLINGER CALIBRATION CHANNELS TO
                          ENGINEERING UNITS,CH1-6 DIVIDED BY 5 TO ALLOW
4515        !              FOR DIFFERENT GAINS DURING CALIBRATIONS
4520        !
4525        DATA 0,0,0,0,0,0,0,0,0,0
4530        DATA 0,0,0,0,0,0,0,0
4535        DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
4540        READ Offset(*)! TO CONVERT WURMLINGER CALIBRATION CHANNELS TO
                           ENGINEERING UNITS
4545        !
4550        ! ENGINEERING UNITS FOR WURMLINGER CALIBRATION MEASURED CHANNELS
4555        !
4560        Units$(1)="  MPa"
4565        Units$(2)="  MPa"
4570        Units$(3)="  MPa"
4575        Units$(4)="  MPa"
4580        Units$(5)="  MPa"
4585        Units$(6)="  MPa"
4590        Units$(7)="  kN"
4595        Units$(8)="  kN"
4600        Units$(9)=" "
4605        Units$(10)=" "
4610        Units$(11)="  MPa"
4615        Units$(12)="  MPa"
4620        Units$(13)="  MPa"
4625        Units$(14)="  MPa"
4630        Units$(15)="  MPa"
4635        Units$(16)="  MPa"
4640        Units$(17)="  kN"
4645        Units$(18)="  kN"
4650        !
4655        ! CALCULATED QUANTITES CHANNEL DESCRIPTION WHEN USING CALIB. DATA
4660        !
4665        Channel_desc$(19)="BENDING MOMENT"
4670        Channel_desc$(20)="SPINDLE TORQUE"
4675        Channel_desc$(21)="FORCE"
4680        Channel_desc$(22)="RADIAL LOCATION"
4685        Channel_desc$(23)="CIRCUMFERENTIAL LOCATION"
4690        Channel_desc$(24)="BENDING MOMENT (FILTERED)"
4695        Channel_desc$(25)="SPINDLE TORQUE (FILTERED)"
4700        Channel_desc$(26)="FORCE (FILTERED)"
4705        Channel_desc$(27)="RADIAL LOCATION (FILTERED)"
4710        Channel_desc$(28)="CIRCUMFERENTIAL LOCATION (FILTERED)"
4715        Channel_desc$(29)="NOT APPLICABLE"
4720        Channel_desc$(30)="NOT APPLICABLE"
4725        Channel_desc$(31)="NOT APPLICABLE"
4730        Channel_desc$(32)="NOT APPLICABLE"
4735        Channel_desc$(33)="FFT"
4740        Channel_desc$(34)="NOT APPLICABLE"
4745        Channel_desc$(35)="FILTERED"
4750        !
4755        ! ENGINEERING UNITS FOR DERIVED CHANNELS WHEN USING CALIB. DATA
4760        !
4765        Units$(19)="  kN.m"
```

```
4770      Units$(20)="  kN.m"
4775      Units$(21)="  kN"
4780      Units$(22)="  m"
4785      Units$(23)="  m"
4790      Units$(24)="  kN.m"
4795      Units$(25)="  kN.m"
4800      Units$(26)="  kN"
4805      Units$(27)="  m"
4810      Units$(28)="  m"
4815      Units$(29)=""
4820      Units$(30)=""
4825      Units$(31)=""
4830      Units$(32)=""
4835      Units$(34)=""
4840      Units$(35)="     "
4845     !
4850  !
4855  !     COMMENTS FOR EACH CHANNEL
4860  !
4865      Channel_com$(1)="POS SIG FOR TIP BENDING FORWARD"
4870      Channel_com$(2)="POS SIG FOR TRAIL. EDGE BENDING FWD"
4875      Channel_com$(3)="POS SIG FOR TIP BENDING FORWARD"
4880      Channel_com$(4)="POS SIG FOR TRAIL. EDGE BENDING FWD"
4885      Channel_com$(5)="POS SIG FOR TIP BENDING FORWARD"
4890      Channel_com$(6)="POS SIG FOR TRAIL. EDGE BENDING FWD"
4895      Channel_com$(7)="POS SIG FOR TRAIL. EDGE BENDING FWD"
4900      Channel_com$(8)="POS SIG IS SHAFT IN TENSION"
4905      Channel_com$(9)=" "
4910      Channel_com$(10)=" "
4915      Channel_com$(11)="POS SIG FOR TIP BENDING FORWARD"
4920      Channel_com$(12)="POS SIG FOR TRAIL. EDGE BENDING FWD"
4925      Channel_com$(13)="POS SIG FOR TIP BENDING FORWARD"
4930      Channel_com$(14)="POS SIG FOR TRAIL. EDGE BENDING FWD"
4935      Channel_com$(15)="POS SIG FOR TIP BENDING FORWARD"
4940      Channel_com$(16)="POS SIG FOR TRAIL. EDGE BENDING FWD"
4945      Channel_com$(17)="POS SIG FOR TRAIL. EDGE BENDING FWD"
4950      Channel_com$(18)="POS SIG IS SHAFT IN TENSION"
4955      Channel_com$(19)="POS SIG FOR TIP BENDING FORWARD"
4960      Channel_com$(20)="POS SIG FOR TRAIL. EDGE BENDING FWD"
4965      Channel_com$(21)="POS SIG FOR TIP BENDING FORWARD"
4970      Channel_com$(22)="DISTANCE FROM BLADE ROOT, (0.37 RR)"
4975      Channel_com$(23)="DISTANCE FROM BLADE C.L., LE is POS"
4980      Channel_com$(24)="POS SIG FOR TIP BENDING FORWARD"
4985      Channel_com$(25)="POS SIG FOR TRAIL. EDGE BENDING FWD"
4990      Channel_com$(26)="POS SIG FOR TIP BENDING FORWARD"
4995      Channel_com$(27)="DISTANCE FROM BLADE ROOT, (0.37 RR)"
5000      Channel_com$(28)="DISTANCE FROM BLADE C.L., LE is POS"
5005      Channel_com$(29)=" "
5010      Channel_com$(30)=" "
5015      Channel_com$(31)=" "
5020      Channel_com$(32)=" "
5025      Channel_com$(33)=" "
5030      Channel_com$(34)=" "
5035      Channel_com$(35)=""
5040      !
5045  ELSE
5050     !
5055     ! CHANNEL DESCRIPTION FOR SHIP TESTING AQUIRED CHANNELS
5060     !
5065      Channel_desc$(1)="CENTRE BENDING"
5070      Channel_desc$(2)="TRAILING EDGE TORQUE"
5075      Channel_desc$(3)="LEADING EDGE BENDING"
5080      Channel_desc$(4)="CENTRE TORQUE"
5085      Channel_desc$(5)="TRAILING EDGE BENDING"
5090      Channel_desc$(6)="LEADING EDGE TORQUE"
5095      Channel_desc$(7)="SLIDING BLOCK FORCE"
```

```
5100       IF Test_number<6 THEN
5105          FOR I=0 TO 18
5110             Channel_desc$(I)=" "
5115          NEXT I
5120       ELSE
5125          Channel_desc$(8)="SHAFT THRUST"
5130          Channel_desc$(9)="SHAFT TORQUE"
5135          Channel_desc$(10)="SERVO OIL PRESSURE"
5140          Channel_desc$(11)="AFT PORT PROBE"
5145          Channel_desc$(12)="AFT TOP PROBE"
5150          IF Test_number<14 THEN
5155             Channel_desc$(13)="FWD PORT PROBE"
5160          ELSE
5165             Channel_desc$(13)="FUEL RACK"
5170          END IF
5175          Channel_desc$(14)="FWD STRB PROBE"
5180          Channel_desc$(15)="SHAFT RATE PULSE"
5185          Channel_desc$(16)="PROPELLER PITCH"
5190          Channel_desc$(17)="SHIP SPEED"
5195          Channel_desc$(18)="RUDDER ANGLE"
5200       END IF
5205      !
5210 Slope_data:      !
5215       DATA .226,.0615,.226,.0615,.226,.0615,1.222,5.76,.693,.1406
5220       DATA .000624,.000616,.0181,.000623,.005,.0175,.0257,.0798
5225       DATA 1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1
5230       RESTORE Slope_data
5235       READ Slope(*)! TO CONVERT SHIP TESTING ACQUIRED CHANNELS TO
                          ENGINEERING UNITS
5240        !             TORQUE (CHANNEL #9) GAIN INCREASED : .462*1.5=0.693
5245        !
5250        !             TO PUT IN NEW SLIDING BLOCK GAINS
5255        !             AND ALTERNATE GAIN USED WHEN FULL BRIDGE WAS WORKING
5260       IF Test_number<13 THEN Slope(7)=.611
5265       IF Test_number<14 THEN Slope(13)=.000621
5270       IF Test_number<13 THEN Slope(17)=.00257
5275      !
5280 Test_1:     !
5285       DATA 5,0,7,.5,7,0,2,0,0,0
5290       DATA 0,0,0.515,0,0,0,0,0
5295       DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
5300 Test_3:!
5305       DATA 35,-3,50,-7,0,-8,-100,0,0,0
5310       DATA 0,0,0.515,0,0,0,0,0
5315       DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
5320 Test_4:!
5325       DATA 0,0,0,0,-35,-7.4,0,0,0,0
5330     ! DATA 0.164,0.263,0.199,0.907,0,0,0,0          ! OLD OFFSETS
5335       DATA 0.027,0.114,0.057,0.907,0,0,0,0          ! NEW OFFSETS FROM READI
NGS ON DRY DOCK
5340       DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
5345 Test_270:!
5350      ! OFFSET FROM ZERO LEVELS TEST# 270
5355       DATA -7.465,-.159,-6.280,0.381,-2.340,0.098,0,135,1.609,-5.367
5360       DATA 0.910,-.184,0.515,0.998,0,0,0,0
5365       DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
5370       IF Test_number=1 THEN RESTORE Test_1
5375       IF Test_number=3 THEN RESTORE Test_3
5380       IF Test_number>3 AND Test_number<13 THEN RESTORE Test_4
5385       IF Test_number>12 THEN RESTORE Test_270
5390       READ Offset(*)! TO CONVERT SHIP TESTING ACQUIRED CHANNELS
                           TO ENGINEERING UNITS
5395       !
5400       ! ENGINEERING UNITS FOR MEASURED CHANNELS
5405       !
5410       Units$(1)="  MPa"
```

```
5415      Units$(2)=" MPa"
5420      Units$(3)=" MPa"
5425      Units$(4)=" MPa"
5430      Units$(5)=" MPa"
5435      Units$(6)=" MPa"
5440      Units$(7)=" kN"
5445      Units$(8)=" kN"
5450      Units$(9)=" kN.m"
5455      Units$(10)=" bar"
5460      Units$(11)=" mm"
5465      Units$(12)=" mm"
5470      Units$(13)=" mm"
5475      Units$(14)=" mm"
5480      Units$(15)=" volt"
5485      Units$(16)=" deg"
5490      Units$(17)=" m/s"
5495      Units$(18)=" deg"
5500      !
5505      ! CALCULATED QUANTITES CHANNEL DESCRIPTION FOR SHIP TESTS
5510      !
5515      Channel_desc$(19)="BENDING MOMENT"
5520      Channel_desc$(20)="SPINDLE TORQUE"
5525      Channel_desc$(21)="FORCE"
5530      Channel_desc$(22)="RADIAL LOCATION"
5535      Channel_desc$(23)="CIRCUMFERENTIAL LOCATION"
5540      Channel_desc$(24)="BENDING MOMENT (FILTERED)"
5545      Channel_desc$(25)="SPINDLE TORQUE (FILTERED)"
5550      Channel_desc$(26)="FORCE (FILTERED)"
5555      Channel_desc$(27)="RADIAL LOCATION (FILTERED)"
5560      Channel_desc$(28)="CIRCUMFERENTIAL LOCATION (FILTERED)"
5565      Channel_desc$(29)="AFT HORIZONTAL"
5570      Channel_desc$(30)="AFT VERTICAL"
5575      Channel_desc$(31)="FORWARD HORIZONTAL"
5580      Channel_desc$(32)="FORWARD VERTICAL"
5585      Channel_desc$(33)="FFT"
5590      Channel_desc$(34)="SHAFT SPEED"
5595      Channel_desc$(35)="FILTERED"
5600      !
5605      ! ENGINEERING UNITS FOR DERIVED CHANNELS FOR SHIP TESTS
5610      !
5615      Units$(19)=" kN.m"
5620      Units$(20)=" kN.m"
5625      Units$(21)=" kN"
5630      Units$(22)=" m"
5635      Units$(23)=" m"
5640      Units$(24)=" kN.m"
5645      Units$(25)=" kN.m"
5650      Units$(26)=" kN"
5655      Units$(27)=" m"
5660      Units$(28)=" m"
5665      Units$(29)=" mm"
5670      Units$(30)=" mm"
5675      Units$(31)=" mm"
5680      Units$(32)=" mm"
5685      Units$(34)=" RPM"
5690      Units$(35)="     "
5695      !
5700   !
5705   !      COMMENTS FOR EACH CHANNEL
5710   !
5715      Channel_com$(1)="POS SIG FOR TIP BENDING FORWARD"
5720      Channel_com$(2)="POS SIG FOR TRAIL. EDGE BENDING FWD"
5725      Channel_com$(3)="POS SIG FOR TIP BENDING FORWARD"
5730      Channel_com$(4)="POS SIG FOR TRAIL. EDGE BENDING FWD"
5735      Channel_com$(5)="POS SIG FOR TIP BENDING FORWARD"
5740      Channel_com$(6)="POS SIG FOR TRAIL. EDGE BENDING FWD"
```

```
5745  !
5750  !     COMMENTS FOR EACH CHANNEL
5755  !
5760        Channel_com$(1)="POS SIG FOR TIP BENDING FORWARD"
5765        Channel_com$(2)="POS SIG FOR TRAIL. EDGE BENDING FWD"
5770        Channel_com$(3)="POS SIG FOR TIP BENDING FORWARD"
5775        Channel_com$(4)="POS SIG FOR TRAIL. EDGE BENDING FWD"
5780        Channel_com$(5)="POS SIG FOR TIP BENDING FORWARD"
5785        Channel_com$(6)="POS SIG FOR TRAIL. EDGE BENDING FWD"
5790        Channel_com$(7)="POS SIG FOR TRAIL. EDGE BENDING FWD"
5795        Channel_com$(8)="POS SIG IS SHAFT IN TENSION"
5800        Channel_com$(9)="POS SIG IS ENGINE DRIVING SHAFT"
5805        Channel_com$(10)="POS CHANGE INCREASES PITCH ANGLE"
5810        Channel_com$(11)="POS CHANGE ,INCREASING SEPARATION"
5815        Channel_com$(12)="POS CHANGE ,INCREASING SEPARATION"
5820        IF Test_number<14 THEN
5825           Channel_com$(13)="POS CHANGE ,INCREASING SEPARATION"
5830        ELSE
5835           Channel_com$(13)="POS CHANGE ,INCREASING FUEL"
5840        END IF
5845        Channel_com$(14)="POS CHANGE ,INCREASING SEPARATION"
5850        Channel_com$(15)="TEN O'CLOCK LOOKING FORWARD, 1/REV"
5855        Channel_com$(16)="POS SIGNAL ,AHEAD PITCH"
5860        Channel_com$(17)="ABSOLUTE VALUE OF VELOCITY"
5865        Channel_com$(18)="POS SIG IS STBD."
5870        Channel_com$(19)="POS SIG FOR TIP BENDING FORWARD"
5875        Channel_com$(20)="POS SIG FOR TRAIL. EDGE BENDING FWD"
5880        Channel_com$(21)="POS SIG FOR TIP BENDING FORWARD"
5885        Channel_com$(22)="DISTANCE FROM BLADE ROOT, (0.37 RR)"
5890        Channel_com$(23)="DISTANCE FROM BLADE C.L., LE is POS"
5895        Channel_com$(24)="POS SIG FOR TIP BENDING FORWARD"
5900        Channel_com$(25)="POS SIG FOR TRAIL. EDGE BENDING FWD"
5905        Channel_com$(26)="POS SIG FOR TIP BENDING FORWARD"
5910        Channel_com$(27)="DISTANCE FROM BLADE ROOT, (0.37 RR)"
5915        Channel_com$(28)="DISTANCE FROM BLADE C.L., LE is POS"
5920        Channel_com$(29)="POS SIG IS SHAFT TO STBD."
5925        Channel_com$(30)="POS SIG IS SHAFT TO TOP"
5930        Channel_com$(31)="POS SIG IS SHAFT TO STBD."
5935        Channel_com$(32)="POS SIG IS SHAFT TO TOP"
5940        Channel_com$(33)=" "
5945        Channel_com$(34)="ALWAYS POSITIVE"
5950        Channel_com$(35)=""
5955         !
5960     END IF
5965        !
5970        ! 3x6 MATRIX FOR CONVERTING STRAIN GUAGE READINGS INTO FORCES
5975        !
5980        ! A MATRIX ALL CHANNELS, FOR MOST TESTS FROM 1 TO 290, FROM MANUAL
5985        ! FROM MANUAL READINGS CASE 1, NOT USED.
5990        !
5995 A_matrix:      !
6000      DATA -1.404E-2,-7.914E-3,4.934E-2,3.949E-3,2.470E-2,1.204E-2
6005      DATA +7.680E-3,+1.690E-3,-6.067E-2,-1.679E-2,+6.203E-2,+2.299E-4
6010      DATA -1.765E-1,-1.391E-3,1.791E-1,1.393E-2,1.217E-1,2.199E-2
6015        !
6020        ! A MATRIX FOR CHANNEL 6 DEAD, USING ALL DATA .59<= RADIUS <=.99
6025        ! AND .01<= CHORD <=.99 , USED FOR TEST # 7
6030        !
6035      DATA -7.715E-3,-7.151E-3,2.690E-2,4.735E-3,3.890E-2,0  !BENDING MOMENT
6040      DATA +8.053E-3,+1.760E-3,-5.970E-2,-1.667E-2,+6.045E-2,0  !SPINDLE TORQUE
6045      DATA -1.570E-1,-1.639E-2,1.262E-1,1.554E-2,1.524E-1,0  ! FORCE
6050        !
6055        ! A MATRIX FOR CHANNEL 4 DEAD ,FOR TESTS 299 TO 343 , FROM CASE 1
6060        ! MANUAL DATA, NOT USED.
6065        !
6070      DATA -1.529E-2,-3.930E-4,4.541E-2,0,2.966E-2,1.152E-2  !BENDING MOMENT
```

```
6075   DATA +7.897E-3,+1.898E-3,-5.926E-2,-1.666E-2,+6.008E-2,2.795E-4
6080   DATA -1.736E-1,-2.528E-3,1.789E-1,1.618E-2,1.160E-1,2.810E-2
6085     !
6090     ! A MATRIX FOR CHANNEL 4 DEAD, USING ALL DATA .59<= RADIUS <=.99
6095     ! AND .01<= CHORD <=.99
6100     ! USED FOR TEST NUMBERS: 299-343.
6105     !
6110   DATA -1.524E-2,-8.278E-4,4.430E-2,0,3.008E-2,1.127E-2  !BENDING MOMENT
6115   DATA 1.127E-2,-3.853E-5,-4.428E-2,0,3.945E-2,1.517E-3  !SPINDLE TORQUE
6120   DATA -1.768E-1,-6.473E-4,1.644E-1,0,1.360E-1,2.690E-2  !FORCE
6125     !
6130     ! A MATRIX FOR CHANNEL 2 DEAD, USING ALL DATA .59<= RADIUS <=.99
6135     ! AND .01<= CHORD <=.99 .
6140     ! USED FOR TEST NUMBERS: 45-49; 52-54; 56-64; 66-73; 77-96, and 111-120
6145     !
6150   DATA -1.450E-2,0,5.136E-2,4.917E-3,2.130E-2,1.283E-2  !BENDING MOMENT
6155   DATA 8.268E-3,0,-6.271E-2,-1.655E-2,6.356E-2,1.319E-3  !SPINDLE TORQUE
6160   DATA -1.740E-1,0,1.835E-1,1.603E-2,1.114E-1,3.023E-2  !FORCE
6165     !
6170   RESTORE A_matrix
6175   READ A_matrix(*)
6180     !
6185     !A MATRIX GENERATED BY MATRIXTEST ASSUMS THAT VOLTAGE IS IN mV
6190     !BUT 6940b LSB =5mV.
6195     ! HOWEVER FOR THE CALIBRATION TESTS THE GAIN WAS 5 TIMES THE GAIN
6200     ! USED DURING THE MANUAL CALIBRATIONS AND ACTUAL TESTS ;THEREFORE
6205     ! ONLY MULTIPLY A MATRIX BY 5 FOR THE ACTUAL TESTS
6210     !IN MATRIXTEST UNIT OF LENGTH IS mm SO TO USE M THE 1st &2nd ROW
6215     !IN THE READ STATMENT HAVE BEEN MULTIPLIED BY 10^-3
6220     !HAVE MUTIPLIED TORQUE ROW BY -1 TO MAKE ANTICLOCKWISE TORQUE ,
6225     !LOOKING FROM ABOVE BLADE,+ve
6230     !
6235   IF NOT Calib_data THEN MAT A_matrix= A_matrix*(5)
6240     ! SCALE FACTORS FOR CALCULATED VALUES - CONVERSION TO INTEGERS
6245     !
6250   DATA 1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1
6255   DATA 25,25,25,1000,1000,25,25,25,1000,1000,1000,1000,1000,1000,100,10,1
6260   READ Scale_factor(*)
6265     !
6270   RETURN
6275   !
6280  ! ==============================================================
6285  ! FIX_CALIB_GAIN
6290  ! ==============================================================
6295 Fix_calib_gain: !
6300   ! THE 35 IS A CORRECTION FOR THE NUMBER OF L.S.B. THAT THE SIGNAL WAS OFF
6305   ! THE POSITIVE AND NEGATIVE GAINS ARE CORRECTED BY THE RATIOS
6310   Pos_ch7_cor=48.8/122.2              ! SCALES FOR SLIDING BLOCK SIGNAL
6315   Neg_ch7_cor=178/122.2
6320   !
6325   DISP "FIXING GAINS"
6330   FOR I=1 TO Nscans
6335      Signals(7,I)=Signals(7,I)-35
6340      IF Signals(7,I)<0 THEN
6345         Signals(7,I)=INT(Signals(7,I)*Neg_ch7_cor+.5)
6350      ELSE
6355         Signals(7,I)=INT(Signals(7,I)*Pos_ch7_cor+.5)
6360      END IF
6365      Signals(17,I)=Signals(17,I)-35
6370      IF Signals(17,I)<0 THEN
6375         Signals(17,I)=INT(Signals(17,I)*Neg_ch7_cor+.5)
6380      ELSE
6385         Signals(17,I)=INT(Signals(17,I)*Pos_ch7_cor+.5)
6390      END IF
6395   NEXT I
6400   RETURN
```

```
6405                 !
6410   ! ==========================================================
6415   ! FIX_TEST_GAIN
6420   ! ==========================================================
6425 Fix_test_gain: !
6430                 ! APPROXIMATE SIGNAL OFFSETS IN L.S.B. CORECTIONS
6435   DISP "FIXING GAINS"
6440   IF Test_number=1 THEN
6445      FOR I=1 TO Nscans
6450         Signals(7,I)=Signals(7,I)+300
6455      NEXT I
6460   END IF
6465   IF Test_number>1 AND Test_number<7 THEN
6470      FOR I=1 TO Nscans
6475         Signals(7,I)=Signals(7,I)+300
6480      NEXT I
6485   END IF
6490   IF Test_number >6 AND Test_number<13 THEN
6495      FOR I=1 TO Nscans
6500         Signals(7,I)=0
6505      NEXT I
6510   END IF
6515   IF Test_number>1 AND Test_number<10 THEN
6520      FOR I=1 TO Nscans
6525         Signals(7,I)=-1*Signals(7,I)
6530      NEXT I
6535   END IF
6540   IF Test_number>59 AND Test_number<117 THEN
6545      FOR I=1 TO Nscans
6550         Signals(7,I)=0
6555      NEXT I
6560   END IF
6565   IF Test_number=44 THEN
6570      FOR I=2260 TO 2277
6575         Signals(2,I)=Signals(2,2259)
6580      NEXT I
6585   END IF
6590   IF Test_number=53 THEN Signals(7,1131)=Signals(7,1130)
6595   IF Test_number=55 THEN
6600      FOR I=5513 TO 5537
6605         Signals(2,I)=Signals(2,5512)
6610      NEXT I
6615   END IF
6620   IF Test_number=58 THEN
6625      FOR I=4749 TO 4761
6630         Signals(7,I)=Signals(7,4748)
6635      NEXT I
6640      Signals(7,4773)=Signals(7,4772)
6645      Signals(7,4774)=Signals(7,4772)
6650      Signals(7,5070)=Signals(7,5069)
6655      Signals(7,5071)=Signals(7,5069)
6660      Signals(7,5394)=Signals(7,5393)
6665   END IF
6670   IF Test_number=69 THEN
6675      Signals(1,2144)=Signals(1,2143)
6680      Signals(1,3222)=Signals(1,3221)
6685      Signals(1,3329)=Signals(1,3328)
6690      Signals(3,772)=Signals(3,771)
6695      Signals(3,1207)=Signals(3,1206)
6700      Signals(3,3664)=Signals(3,3663)
6705      Signals(3,5999)=Signals(3,5998)
6710      Signals(4,305)=Signals(4,304)
6715      Signals(4,416)=Signals(4,415)
6720      Signals(4,3148)=Signals(4,3147)
6725      Signals(5,886)=Signals(5,885)
6730      Signals(5,1707)=Signals(5,1706)
```

```
6735       Signals(5,2039)=Signals(5,2038)
6740       Signals(5,2586)=Signals(5,2585)
6745       Signals(5,1503)=Signals(5,1502)
6750       Signals(6,2199)=Signals(6,2198)
6755       Signals(6,2302)=Signals(6,2301)
6760       Signals(6,3330)=Signals(6,3329)
6765       Signals(8,352)=Signals(8,351)
6770       Signals(8,623)=Signals(8,622)
6775       Signals(8,1128)=Signals(8,1127)
6780       Signals(8,1960)=Signals(8,1959)
6785       Signals(8,2115)=Signals(8,2114)
6790       Signals(8,3739)=Signals(8,3738)
6795       Signals(10,985)=Signals(10,984)
6800       Signals(10,1372)=Signals(10,1371)
6805       Signals(13,2585)=Signals(13,2584)
6810       Signals(13,3536)=Signals(13,3535)
6815       Signals(12,536)=Signals(12,535)
6820       Signals(12,1433)=Signals(12,1432)
6825       Signals(12,1444)=Signals(12,1443)
6830       Signals(12,2867)=Signals(12,2866)
6835       Signals(16,2484)=Signals(16,2483)
6840       Signals(16,3670)=Signals(16,3669)
6845       Signals(17,1835)=Signals(17,1834)
6850       Signals(17,2493)=Signals(17,2492)
6855       Signals(17,2674)=Signals(17,2673)
6860       Signals(17,2852)=Signals(17,2851)
6865       Signals(18,931)=Signals(18,930)
6870       Signals(18,3516)=Signals(18,3515)
6875       Signals(18,4117)=Signals(18,4116)
6880    END IF
6885    IF Test_number=92 THEN
6890       Signals(13,2131)=Signals(13,2130)
6895       Signals(16,2185)=Signals(16,2184)
6900       Signals(17,4915)=Signals(17,4914)
6905    END IF
6910    IF Test_number>116 AND Test_number<124 THEN
6915       FOR I=1 TO Nscans
6920          Signals(7,I)=Signals(7,I)+51
6925       NEXT I
6930    END IF
6935    IF Test_number=147 THEN
6940       Signals(1,211)=Signals(1,210)
6945       Signals(1,1289)=Signals(1,1288)
6950       Signals(1,1396)=Signals(1,1395)
6955       Signals(2,1284)=Signals(2,1283)
6960       Signals(2,1383)=Signals(2,1382)
6965       Signals(2,2351)=Signals(2,2350)
6970       Signals(3,1731)=Signals(3,1730)
6975       Signals(3,4066)=Signals(3,4065)
6980       Signals(4,1008)=Signals(4,1007)
6985       Signals(4,3303)=Signals(4,3302)
6990       Signals(5,106)=Signals(5,105)
6995       Signals(5,653)=Signals(5,652)
7000       Signals(6,698)=Signals(6,697)
7005       Signals(6,1335)=Signals(6,1334)
7010       Signals(6,1397)=Signals(6,1396)
7015       Signals(7,767)=Signals(7,766)
7020       Signals(7,2988)=Signals(7,2987)
7025       Signals(8,27)=Signals(8,26)
7030       Signals(8,182)=Signals(8,181)
7035       Signals(8,1389)=Signals(8,1388)
7040       Signals(8,1806)=Signals(8,1805)
7045       Signals(10,199)=Signals(10,198)
7050       Signals(10,1550)=Signals(10,1549)
7055       Signals(13,358)=Signals(13,357)
7060       Signals(13,592)=Signals(13,591)
```

```
7065        Signals(13,1603)=Signals(13,1602)
7070        Signals(16,551)=Signals(16,550)
7075        Signals(16,1737)=Signals(16,1736)
7080        Signals(16,4200)=Signals(16,4199)
7085        Signals(17,560)=Signals(17,559)
7090        Signals(17,741)=Signals(17,740)
7095        Signals(17,919)=Signals(17,918)
7100        Signals(17,5666)=Signals(17,5665)
7105        Signals(18,22)=Signals(18,21)
7110        Signals(18,1583)=Signals(18,1582)
7115     END IF
7120     IF Test_number>123 AND Test_number<188 THEN
7125        FOR I=1 TO Nscans
7130           Signals(7,I)=Signals(7,I)+110
7135        NEXT I
7140     END IF
7145     IF Test_number>187 AND Test_number<210 THEN
7150        FOR I=1 TO Nscans
7155           Signals(7,I)=Signals(7,I)+127
7160        NEXT I
7165     END IF
7170     IF Test_number>209 AND Test_number<343 THEN
7175        FOR I=1 TO Nscans
7180           Signals(7,I)=Signals(7,I)+165
7185        NEXT I
7190     END IF
7195     ! CORECTIONS OF CH.7 AND CH.16 GAINS FOR POS AND NEG SIGNALS
7200     Pos_ch7_cor=48.8/122.2              ! SCALES FOR SLIDING BLOCK SIGNAL
7205     Neg_ch7_cor=178/122.2/10            ! THERE IS NO EXPLAINATION FOR THE
                                               FACTOR OF 10, BUT IT WORKS !!
7210     !
7215     IF Test_number>1 AND Test_number<8 THEN
7220        FOR I=1 TO Nscans
7225           IF Signals(7,I)>0 THEN
7230              Signals(7,I)=INT(Signals(7,I)*Neg_ch7_cor+.5)
7235           ELSE
7240              Signals(7,I)=INT(Signals(7,I)*Pos_ch7_cor+.5)
7245           END IF
7250        NEXT I
7255     ELSE
7260        FOR I=1 TO Nscans
7265           IF Signals(7,I)<0 THEN
7270              Signals(7,I)=INT(Signals(7,I)*Neg_ch7_cor+.5)
7275           ELSE
7280              Signals(7,I)=INT(Signals(7,I)*Pos_ch7_cor+.5)
7285           END IF
7290           IF Signals(16,I)<0 THEN
7295              Signals(16,I)=INT(Signals(16,I)*Neg_ch16_cor+.5)
7300           END IF
7305        NEXT I
7310     END IF
7315     RETURN
7320     !
7325     ! ==============================================================
7330     !    MAIN KEYS
7335     ! ==============================================================
7340 Main_keys:    !
7345     OFF KEY
7350     ON KEY 0 LABEL "Xmax Inc / Dec" GOTO Xmaxinc
7355     ON KEY 10 GOTO Xmaxdec
7360     ON KEY 1 LABEL "Ymax Inc / Dec" GOTO Ymaxinc
7365     ON KEY 11 GOTO Ymaxdec
7370     ON KEY 2 LABEL "ADD CH/XY PLOT" GOTO Select_channel
7375     ON KEY 12 GOSUB Plot_type
7380     ON KEY 3 LABEL "FILTER /DESIGN" GOSUB Digital_filter
7385     ON KEY 13 GOSUB Filter_design
```

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7390   ON KEY 4 LABEL "LABEL UP /DOWN" GOSUB Label_up
7395   ON KEY 14 GOSUB Label_down
7400   ON KEY 5 LABEL "Xmin Inc / Dec" GOTO Xmininc
7405   ON KEY 15 GOTO Xmindec
7410   ON KEY 6 LABEL "Ymin Inc / Dec" GOTO Ymininc
7415   ON KEY 16 GOTO Ymindec
7420   ON KEY 7 LABEL "VIEW/SPLITVIEW" GOTO New_plot
7425   ON KEY 17 GOTO Two_plot
7430   ON KEY 8 LABEL "CALC. / HELP" GOSUB Calculate
7435   ON KEY 18,3 GOTO Help
7440   ON KEY 9 LABEL "FFT / STATS" GOSUB Fft
7445   ON KEY 19,3 GOTO Statistics
7450   RETURN
7455  !
7460  ! ============================================================
7465  !  MAIN EXIT
7470  ! ============================================================
7475 Main_exit:    !
7480   Main_exit=1
7485   RETURN
7490  !
7495  ! ========================================================================
7500  ! HELP
7505  ! ========================================================================
7510 Help: !
7515   Hard_copy=0
7520   PRINTER IS 1
7525   PRINT CHR$(12)
7530   GRAPHICS OFF
7535   PRINT "YOU ARE NOW IN THE WONDERFUL WORLD OF 'HELP' . PRESSING A SOFT"
7540   PRINT "KEY BRINGS UP HELP ON THAT FUNCTION. IN ORDER TO GET BACK TO THE"
7545   PRINT "MAIN PROGRAM , PRESS THE 'EXIT' SOFT KEY. THE 'HELP' FEATURE MAY"
7550   PRINT "BE ENTERED AT ANY TIME, A SMALL ROYALTY FEE IS APPLICABLE FOR"
7555   PRINT "EACH USE."
7560   GOSUB Help_keys
7565 Help_loop:GOTO Help_loop
7570 Help_exit:  !
7575   DISP ""
7580   PRINT CHR$(12)
7585   GRAPHICS ON
7590   GOTO Main_loop
7595   !
7600  ! ============================================================
7605  !   HELP KEYS
7610  ! ============================================================
7615 Help_keys:    !
7620   OFF KEY
7625   ON KEY 0 LABEL "Xmax Inc / Dec" GOSUB Xmxin
7630   ON KEY 10 GOSUB Xmxdc
7635   ON KEY 1 LABEL "Ymax Inc / Dec" GOSUB Ymxin
7640   ON KEY 11 GOSUB Ymxdc
7645   ON KEY 2 LABEL "ADD CH/XY PLOT" GOSUB Sel
7650   ON KEY 12 GOSUB Typ
7655   ON KEY 3 LABEL "FILTER /DESIGN" GOSUB Fil
7660   ON KEY 13 GOSUB Fl_des
7665   ON KEY 4 LABEL "LABEL UP /DOWN" GOSUB Lbl_up
7670   ON KEY 14 GOSUB Lbl_dn
7675   ON KEY 5 LABEL "Xmin Inc / Dec" GOSUB Xmnin
7680   ON KEY 15 GOSUB Xmndc
7685   ON KEY 6 LABEL "Ymin Inc / Dec" GOSUB Ymnin
7690   ON KEY 16 GOSUB Ymndc
7695   ON KEY 7 LABEL "VIEW/SPLITVIEW" GOSUB Vw
7700   ON KEY 17 GOSUB Sp_vw
7705   ON KEY 8 LABEL "CALC. / EXIT" GOSUB Calc
7710   ON KEY 18,3 GOTO Help_exit
7715   ON KEY 9 LABEL "FFT / STATS" GOSUB Fft_hp
```

```
7720   ON KEY 19 GOSUB Stat
7725   RETURN
7730   !
7735   ! ====================================================================
7740   ! CUR
7745   ! ====================================================================
7750 Cur: !
7755   Hard_copy=0
7760   PRINTER IS 1
7765   PRINT CHR$(12)
7770   PRINT "THE CURSOR CAN BE MOVED ALONG THE DATA POINTS USING THE 'KNOB'."
7775   PRINT "THE VALUE INCREASES FOR CLOCKWISE ROTATION AND DEREASES FOR"
7780   PRINT "COUNTER-CLOCKWISE ROTATION. THE POINT IS DESIGNATED BY A '+'."
7785   PRINT "THE CURRENT VALUE OF THE POINT IS DISPLAYED AT THE BOTTOM OF THE"
7790   PRINT "SCREEN. IN ORDER TO LABEL THE POINT ON THE GRAPH,USE A 'LABEL UP'"
7795   PRINT "OR 'LABEL DOWN' SOFT KEY. THE 'LABEL UP /DOWN' SOFT KEYS WORK ON"
7800   PRINT "ALL TYPES OF PLOTS. THE CURSOR WILL ONLY GOTO POINTS ACTUALLY"
7805   PRINT "PLOTTED ON THE GRAPHS. THE CURSOR WILL AUTOMATIALLY WRAP ARROUND"
7810   PRINT "TO THE OTHER END OF THE DATA WHEN IT EXCEEDS A LIMIT."
7815   GOSUB Lbl_warning
7820   RETURN
7825   !
7830   ! =========================================================
7835   !    MOVE CURSOR
7840   ! =========================================================
7845 Move_cursor:     !
7850   PEN 0
7855   Fft_flag=0
7860   IF Time_plot THEN
7865      IF Channel_y>28 AND Channel_y<33 THEN
7870         GOSUB Channel_y_29
7875      ELSE
7880         IF Channel_y=33 THEN
7885            GOSUB Channel_y_33
7890         ELSE
7895            Disp_x=Current_record*Corr_factor
7900            Disp_y=Signals(Channel_y,Current_record)/Scale_factor(Channel_di
sp_y)*Slope(Channel_disp_y)+Offset(Channel_disp_y)
7905            MOVE Disp_x,Disp_y
7910            LABEL "+"
7915            Knob_value=KNOBX*MAX(.5,ABS(X_time_min-X_time_max))
7920            Current_record=Current_record+Knob_value
7925            Xmin_temp=MAX(1,INT((Xmin+1)/Corr_factor))
7930            Xmax_temp=MIN(INT(Xmax/Corr_factor),Nscans)
7935            IF Current_record<=Xmin_temp THEN Current_record=Xmax_temp
7940            IF Current_record>Xmax_temp THEN Current_record=Xmin_temp
7945            Disp_x=Current record*Corr_factor
7950            Disp_y=Signals(Channel_y,Current_record)/Scale_factor(Channel_di
sp_y)*Slope(Channel_disp_y)+Offset(Channel_disp_y)
7955            MOVE Disp_x,Disp_y
7960            DISP USING "K";I$,Disp_x/1000," s  ",Disp_y,Units$(Channel_disp_
y),N$
7965            LABEL "+"
7970         END IF
7975      END IF
7980   ELSE
7985      IF Channel_y=33 THEN
7990         DISP "I'LL LET YOU AWAY WITH IT, BUT FFT CAN ONLY BE PLOTTED VERSES
 TIME"
7995         BEEP
8000         WAIT 2
8005         GOSUB Channel_y_33
8010      ELSE
8015         IF Channel_x=33 THEN
8020            DISP "FFT CAN ONLY BE PLOTTED ON Y-AXIS VERSES TIME...TRY AGAIN"
8025            BEEP
```

```
8030            WAIT 2
8035         ELSE
8040            Disp_x=Signals(Channel_x,Current_record)/Scale_factor(Channel_di
sp_x)*Slope(Channel_disp_x)+Offset(Channel_disp_x)
8045            Disp_y=Signals(Channel_y,Current_record)/Scale_factor(Channel_di
sp_y)*Slope(Channel_disp_y)+Offset(Channel_disp_y)
8050            MOVE Disp_x,Disp_y
8055            LABEL "+"
8060            Current_record=Current_record+KNOBX
8065            IF Current_record<Start_record THEN Current_record=Stop_record
8070            IF Current_record>Stop_record THEN Current_record=Start_record
8075            Disp_x=Signals(Channel_x,Current_record)/Scale_factor(Channel_di
sp_x)*Slope(Channel_disp_x)+Offset(Channel_disp_x)
8080            Disp_y=Signals(Channel_y,Current_record)/Scale_factor(Channel_di
sp_y)*Slope(Channel_disp_y)+Offset(Channel_disp_y)
8085            MOVE Disp_x,Disp_y
8090            DISP USING "K";I$,Disp_x,Units$(Channel_disp_x),"  ",Disp_y;Unit
s$(Channel_disp_y)," ",(Current_record-1)/Scan_rate,"s ",N$
8095            LABEL "+"
8100         END IF
8105      END IF
8110   END IF
8115   PEN 1
8120   RETURN
8125   ! ==================================================================
8130   ! MOVE CURSOR ROUTINE FOR PROBE PLOTS
8135   ! ====================================================================
8140 Channel_y_29:  !
8145                !
8150   Disp_x=Signals(Channel_y,Current_record)/Scale_factor(Channel_y)*Slope(Ch
annel_y)+Offset(Channel_y)
8155   Disp_y=Signals(Channel_y+1,Current_record)/Scale_factor(Channel_y)*Slope(
Channel_y)+Offset(Channel_y)
8160   MOVE Disp_x,Disp_y
8165   LABEL "+"
8170   Current_record=Current_record+KNOBX
8175   IF Current_record<Start_index THEN Current_record=Stop_index
8180   IF Current_record>Stop_index THEN Current_record=Start_index
8185   Disp_x=Signals(Channel_y,Current_record)/Scale_factor(Channel_y)*Slope(Ch
annel_y)+Offset(Channel_y)
8190   Disp_y=Signals(Channel_y+1,Current_record)/Scale_factor(Channel_y)*Slope(
Channel_y)+Offset(Channel_y)
8195   MOVE Disp_x,Disp_y
8200   DISP USING "K";I$,Disp_x,Units$(Channel_y),"  ",Disp_y,Units$(Channel_y+1
)," ",(Current_record-1)/Scan_rate,"s ",N$
8205   LABEL "+"
8210   RETURN
8215  !
8220  ! ============================================================
8225  !   MOVE CURSOR ROUTINE FOR CHANNEL NO 33 (FFT)
8230  ! ============================================================
8235 Channel_y_33: !
8240   I$=CHR$(129)
8245   N$=CHR$(128)
8250   Fft_flag=1
8255   MOVE Current_value*Scan_rate/Nn,Signals(33,Fft_min+1+Current_value)/Scale
_factor(33)
8260   LABEL "+"
8265   Knob_value=KNOBX*MAX(Max_frequency*.1,1)
8270   Current_value=Current_value+SGN(Knob_value)
8275   IF Current_value<0 THEN Current_value=Current_value+INT(.5+Max_frequency*
Nn/Scan_rate)
8280   IF Current_value>INT(.5+Max_frequency*Nn/Scan_rate) THEN Current_value=Cu
rrent_value-INT(.5+Max_frequency*Nn/Scan_rate)
8285   MOVE Current_value*Scan_rate/Nn,Signals(33,Fft_min+1+Current_value)/Scale
_factor(33)
```

```
8290   DISP USING "5A,A,DDD.D,5A,DDD.D,3A,A";"     ",I$,Current_value*Scan_rate/
Nn," Hz  ",Signals(33,Fft_min+1+Current_value)/Scale_factor(33)," % ",N$
8295   LABEL "+"
8300   RETURN
8305   !
8310   ! ======================================================================
8315   ! XMXIN
8320   ! ======================================================================
8325 Xmxin:!
8330   PRINT CHR$(12)
8335   PRINT "THE Xmaxinc SOFT KEY IS USED TO INCREASE THE MAXIMUM VALUE OF"
8340   PRINT "THE X-AXIS. THIS ONLY WORXS FOR X VERSES Y PLOTTING."
8345   GOSUB Lbl_warning
8350   RETURN
8355   !
8360   ! =============================================================
8365   !    X MAX INCREASE
8370   ! =============================================================
8375 Xmaxinc:    !
8380   IF Time_plot OR Channel_y=33 THEN Main_sub_loop
8385   IF I_xmax<14 THEN
8390      I_xmax=I_xmax+1
8395   ELSE
8400      I_xmax=2
8405      Power_xmax=Power_xmax+1
8410   END IF
8415   GOTO Plot_set_up
8420   !
8425   ! ======================================================================
8430   ! XMXDC
8435   ! ======================================================================
8440 Xmxdc:!
8445   PRINT CHR$(12)
8450   PRINT "THE Xmaxdec SOFT KEY IS USED TO DECREASE THE MAXIMUM VALUE OF"
8455   PRINT "THE X-AXIS. THIS ONLY WORKS FOR X VERSES Y PLOTTING."
8460   GOSUB Lbl_warning
8465   RETURN
8470   !
8475   ! =============================================================
8480   !    X MAX DECREASE
8485   ! =============================================================
8490 Xmaxdec:    !
8495   IF Time_plot OR Channel_y=33 THEN Main_sub_loop
8500   IF I_xmax>1 THEN
8505      I_xmax=I_xmax-1
8510   ELSE
8515      I_xmax=13
8520      Power_xmax=Power_xmax-1
8525   END IF
8530   GOTO Plot_set_up
8535   !
8540   ! ======================================================================
8545   ! XMNDC
8550   ! ======================================================================
8555 Xmndc:!
8560   PRINT CHR$(12)
8565   PRINT "THE Xmindec SOFT KEY IS USED TO DECREASE THE MINIMUM VALUE OF THE"
8570   PRINT "X-AXIS. THIS ONLY WORKS ON X VERSES Y PLOTTING."
8575   GOSUB Lbl_warning
8580   RETURN
8585   !
8590   ! =============================================================
8595   !    X MIN DECREASE
8600   ! =============================================================
8605 Xmindec:    !
8610   IF Time_plot OR Channel_y=33 THEN Main_sub_loop
```

```
8615   IF I_xmin<14 THEN
8620      I_xmin=I_xmin+1
8625   ELSE
8630      I_xmin=2
8635      Power_xmin=Power_xmin+1
8640   END IF
8645   GOTO Plot_set_up
8650  !
8655  ! ==================================================================
8660  ! XMNIN
8665  ! ==================================================================
8670 Xmnin:!
8675   PRINT CHR$(12)
8680   PRINT "THE Xmininc SOFT KEY INCREASES THE MINIMUM VALUE OF THE X AXIS."
8685   PRINT "THIS ONLY WORKS FOR X VERSES Y PLOTTING."
8690   GOSUB Lbl_warning
8695   RETURN
8700  !
8705  ! ============================================================
8710  !    X MIN INCREASE
8715  ! ============================================================
8720 Xmininc:     !
8725   IF Time_plot OR Channel_y=33 THEN Main_sub_loop
8730   IF I_xmin>1 THEN
8735      I_xmin=I_xmin-1
8740   ELSE
8745      I_xmin=13
8750      Power_xmin=Power_xmin-1
8755   END IF
8760   GOTO Plot_set_up
8765  !
8770  ! ==================================================================
8775  ! YMXIN
8780  ! ==================================================================
8785 Ymxin:!
8790   PRINT CHR$(12)
8795   PRINT "THE Ymaxinc SOFT KEY INREASES THE MAXIMUM VALUE OF THE Y-AXIS"
8800   GOSUB Lbl_warning
8805   RETURN
8810  !
8815  ! ============================================================
8820  !    Y MAX INCREASE
8825  ! ============================================================
8830 Ymaxinc:     !
8835   IF Channel_y=33 THEN Main_sub_loop
8840   IF I_ymax<14 THEN
8845      I_ymax=I_ymax+1
8850   ELSE
8855      I_ymax=2
8860      Power_ymax=Power_ymax+1
8865   END IF
8870   GOTO Plot_set_up
8875  !
8880  ! ==================================================================
8885  ! YMXDC
8890  ! ==================================================================
8895 Ymxdc:!
8900   PRINT CHR$(12)
8905   PRINT "THE Ymaxdec SOFT KEY DECREASES THE MAXIMUM VALUE OF THE Y-AXIS."
8910   GOSUB Lbl_warning
8915   RETURN
8920  !
8925  ! ============================================================
8930  !    Y MAX DECREASE
8935  ! ============================================================
8940 Ymaxdec:     !
```

```
8945   IF Channel_y=33 THEN Main_sub_loop
8950   IF I_ymax>1 THEN
8955      I_ymax=I_ymax-1
8960   ELSE
8965      I_ymax=13
8970      Power_ymax=Power_ymax-1
8975   END IF
8980   GOTO Plot_set_up
8985  !
8990  ! ===================================================================
8995  ! YMNDC
9000  ! ===================================================================
9005 Ymndc:!
9010   PRINT CHR$(12)
9015   PRINT "THE Ymindec SOFT KEY DECREASES THE MINIMUM VALUE OF THE Y-AXIS"
9020   GOSUB Lbl_warning
9025   RETURN
9030  !
9035  ! =============================================================
9040  !    Y MIN DECREASE
9045  ! =============================================================
9050 Ymindec:     !
9055   IF Channel_y=33 THEN Main_sub_loop
9060   IF I_ymin<14 THEN
9065      I_ymin=I_ymin+1
9070   ELSE
9075      I_ymin=2
9080      Power_ymin=Power_ymin+1
9085   END IF
9090   GOTO Plot_set_up
9095  !
9100  ! ===================================================================
9105  ! YMNIN
9110  ! ===================================================================
9115 Ymnin:!
9120   PRINT CHR$(12)
9125   PRINT "THE Ymininc SOFT KEY INCREASES THE MINIMUM VALUE OF THE Y-AXIS."
9130   GOSUB Lbl_warning
9135   RETURN
9140  !
9145  ! =============================================================
9150  !    Y MIN INCREASE
9155  ! =============================================================
9160 Ymininc:     !
9165   IF Channel_y=33 THEN Main_sub_loop
9170   IF I_ymin>1 THEN
9175      I_ymin=I_ymin-1
9180   ELSE
9185      I_ymin=13
9190      Power_ymin=Power_ymin-1
9195   END IF
9200   GOTO Plot_set_up
9205  !
9210  ! =============================================================
9215  !    PAGE HEADER
9220  ! =============================================================
9225 Page_header:     !
9230   Today$=DATE$(TIMEDATE)
9235   Time_today$=TIME$(TIMEDATE)
9240   RETURN
9245  !
9250  ! =============================================================
9255  !    SET TIME
9260  ! =============================================================
9265 Set_time:     !
9270   INPUT "ENTER DATE IN FORMAT DD MMM YYYY",Input_date$
```

```
9275    INPUT "ENTER TIME IN FORMAT HH:MM:SS",Input_time$
9280    SET TIMEDATE DATE(Input_date$)+TIME(Input_time$)
9285    RETURN
9290   !
9295   ! ================================================================
9300   !    CALB CHANNEL LIST
9305   ! ================================================================
9310 Calb_chan_list:    !
9315    Calib_data=1
9320    GOTO Channel_list
9325   !
9330   ! ================================================================
9335   !    TEST CHANNEL LIST
9340   ! ================================================================
9345 Test_chan_list:    !
9350    Calib_data=0
9355    Test_number=14
9360    INPUT "ENTER THE TEST # YOU WANT LISTING FOR: Test_number or CONT",Test_n
umber
9365 Channel_list:  !
9370    GOSUB Recorded_ch_des
9375    Tab_desc=4
9380    Tab_units=39
9385    Tab_com=46
9390    GOSUB Hardcopy
9395    IF Hard_copy THEN
9400       PRINT ""
9405       PRINT "                "
9410       PRINT "




             "
9415    END IF
9420    IF Calib_data THEN
9425       PRINT TAB(20);"CHANNEL LISTINGS FOR CALIBRATION DATA"
9430    ELSE
9435       PRINT TAB(20);"CHANNEL LISTINGS FOR ACTUAL TEST DATA"
9440    END IF
9445    PRINT " # ";TAB(Tab_desc);"CHANNEL DESCRIPTIONS";TAB(Tab_units);"UNITS";T
AB(Tab_com);"COMMENTS"
9450    PRINT "-------------------------------------------------------------------
------------"
9455    PRINT
9460    PRINT "       AQUIRED CHANNELS"
9465    PRINT
9470    FOR I=1 TO 18
9475       Num$[1,2]=VAL$(I)
9480       PRINT Num$;TAB(Tab_desc);Channel_desc$(I);TAB(Tab_units);Units$(I);TAB
(Tab_com);Channel_com$(I)
9485    NEXT I
9490    PRINT
9495    PRINT "      CALCULATED QUANTITIES"
9500    PRINT
9505    FOR I=19 TO Total_channels
9510       Num$[1,2]=VAL$(I)
9515       PRINT Num$;TAB(Tab_desc);Channel_desc$(I);TAB(Tab_units);Units$(I);TAB
(Tab_com);Channel_com$(I)
9520    NEXT I
9525    IF Hard_copy THEN PRINT CHR$(12)
9530    Hard_copy=0
9535    PRINTER IS 1
9540    RETURN
9545    !
9550    ! ===================================================================
9555   ! FFT HP
9560   ! =================================================================
9565 Fft_hp:  !
9570   PRINT CHR$(12)
9575   PRINT "THE 'FFT' SOFT KEY PERFORMES A FAST FOURIER TRANSFORM ON THE DATA"
9580   PRINT "PRESENTLY PLOTTED ON THE SCREEN VERSES TIME. THE FFT STARTS AT"
9585   PRINT "THE MINIMUM VALUE OF TIME CURRENTLY PLOTTED. THE NUMBER OF DATA"
9590   PRINT "POINTS INCLUDED IN THE FFT MUST BE A MULTIPLE OF 2, THE POSSIBLE"
9595   PRINT "CHOICES ARE LISTED WHEN THEIR INPUT IS REQUIRED. THE TWO DATA"
9600   PRINT "SOURCES WERE RECORDED AT DIFFERENT SCAN RATES. THE CALIBRATION"
9605   PRINT "DATA WAS RECORDED AT APPROXIMATELY 2000 READINGS PER SECOND WHILE"
9610   PRINT "THE ACTUAL TEST DATA WAS RECORDED AT APPROXIMATELY 1000 READINGS"
9615   PRINT "PER SECOND. THEREFORE THE DURATION OF THE SIGNAL FOR WHICH THE"
9620   PRINT "FFT IS PERFORMED IS DETERMINED BY THE SCAN RATE AND THE NUMBER OF"
9625   PRINT "POINTS INCLUDED IN THE FFT. THE NUMBER OF  POINTS IN THE FOURIER"
9630   PRINT "TRANSFORM IS PROPORTIONAL TO THE NUMBER OF POINTS IN THE INPUT"
9635   PRINT "DATA. THE LONGEST FFT POSSIBLE TAKES ABOUT 4 MINUTES TO CALCULATE"
9640   PRINT "THE DC COMPONENT OF THE FFT IS SUBTRACTED BEFORE THE FFT IS"
9645   PRINT "DISPLAYED. THE GRAPHICAL OUTPUT REPRESENTS THE RELATIVE MAGNITUDE"
9650   PRINT "OF THE VECTOR LENGTH OF THE REAL+IMAGINARY PARTS OF THE FFT."
9655   PRINT "THE GREATEST VETOR LENGTH IS GIVEN AS 100%"
9660   DISP " <<<<<<<<<<< PRESS CONT FOR NEXT PAGE >>>>>>>>>>>>>>>>"
9665   PAUSE
9670   PRINT "THE OUTPUT OF THE LAST FFT PERFORMED IS VIEWED BY PLOTTING"
9675   PRINT "CHANNEL 33."
9680   RETURN
9685   !
9690   ! =======================================================
9695   !    FFT
9700   ! =======================================================
9705 Fft:    !
9710   IF Time_plot THEN
9715      Nn=512
9720      PRINT
9725      PRINT
9730      PRINT
9735      PRINT
9740      PRINT "FFT TAKES APROX 1 min TO CALCULATE 1024 POINTS"
9745      PRINT """PROPDATA"",SCANS AT APROX 1000 Hz,""DYNAMICXX"",SCANS AT APRO
X 2000 Hz"
9750      PRINT "ENTER # OF POINTS IN FFT (32,64,128,256,512,1024,2048,4096)",Nn
9755      INPUT Nn
9760      PRINT CHR$(12)
9765      R=INT((LOG(Nn)/LOG(2))+1.E-6)
9770      IF (Nn-1+INT((Xmin+1)/Corr_factor))>Nscans THEN
9775         BEEP
9780         DISP "SELECTED FFT POINTS EXTEND BEYOND END OF DATA :SELECT FFT AGA
IN"
9785         RETURN
9790      END IF
9795      IF Nn<32 OR Nn>4096 THEN Fft
9800      IF INT(2^R+.005)<>Nn THEN Fft
9805      ALLOCATE INTEGER Shuffle2(0:Nn-1)
9810      ALLOCATE REAL Y(0:Nn-1)
9815      ALLOCATE REAL Y2(0:Nn-1)
9820      ALLOCATE REAL Wu(0:2048,1:2)           ! TEMP. MATRIX FOR FFT
9825      Fft_no=Channel_y
9830      Fft_min=INT(Xmin/Corr_factor)
9835      MAT Y2= (0)
9840      DISP "CALCULATING FFT, PLEASE WAIT"
9845      FOR Q=0 TO Nn-1
9850         Y(Q)=Signals(Channel_y,Q+INT((Xmin+1)/Corr_factor))
9855      NEXT Q
9860      IF Channel_y<19 THEN
9865         MAT Y= Y*(Slope(Channel_y))
9870         MAT Y= Y-(Offset(Channel_y))
```

```
 9875     END IF
 9880     Array_mean=SUM(Y)/SIZE(Y,1)
 9885     MAT Y= Y-(Array_mean)
 9890     FOR I=1 TO R
 9895        Shuffle1(I)=2^(I-1)
 9900     NEXT I
 9905     FOR I=0 TO (Nn/4-1)
 9910        FOR J=1 TO R
 9915           Shuffle2(I)=Shuffle2(I)+Shuffle1(J)*BIT(I,R-J)
 9920        NEXT J
 9925        Shuffle2(I+Nn/4)=Shuffle2(I)+2
 9930        Shuffle2(I+Nn/2)=Shuffle2(I)+1
 9935        Shuffle2(I+Nn/2+Nn/4)=Shuffle2(I)+3
 9940     NEXT I
 9945     MAT REORDER Y BY Shuffle2
 9950     RAD
 9955     FOR S=1 TO R
 9960        L=2^(S-1)
 9965        P=2^(R-S)
 9970        Temp1=-P*2*PI*(1/Nn)
 9975        FOR Q=0 TO L-1
 9980           Wu(Q,1)=COS(Temp1*Q)
 9985           Wu(Q,2)=SIN(Temp1*Q)
 9990        NEXT Q
 9995        FOR I=0 TO Nn-2*L STEP 2*L
10000           FOR Q=0 TO L-1
10005              J=I+Q
10010              Mm=J+L
10015              R1=Y(Mm)*Wu(Q,1)-Y2(Mm)*Wu(Q,2)
10020              R2=Y(Mm)*Wu(Q,2)+Y2(Mm)*Wu(Q,1)
10025              Y(Mm)=Y(J)-R1
10030              Y2(Mm)=Y2(J)-R2
10035              Y(J)=Y(J)+R1
10040              Y2(J)=Y2(J)+R2
10045           NEXT Q
10050        NEXT I
10055     NEXT S
10060 Fold_over:       !
10065     Inverse=2/Nn
10070     Amplitude=0
10075     FOR Q=0 TO (Nn/2)
10080        Wu(Q,1)=Inverse*SQR(Y(Q)^2+Y2(Q)^2)
10085        Amplitude=MAX(Amplitude,Wu(Q,1))
10090     NEXT Q
10095     Wu(0,1)=Wu(0,1)/2
10100     Wu(Nn/2,1)=Wu(Nn/2,1)/2
10105     Temp1=100/Amplitude
10110     FOR Q=0 TO Nn/2
10115        Signals(33,Q+INT((Xmin+1)/Corr_factor))=INT(Wu(Q,1)*Temp1+.5)*Scale
_factor(33)
10120     NEXT Q
10125     DISP "TO VIEW THE FFT OUTPUT, PLOT CHANNEL 33 VERSES TIME"
10130     BEEP
10135     DEG
10140     DEALLOCATE Wu(*)
10145     DEALLOCATE Shuffle2(*)
10150     DEALLOCATE Y(*)
10155     DEALLOCATE Y2(*)
10160 ELSE
10165     DISP "FFT CAN ONLY BE PERFORMED ON DATA PLOTTED VERSES TIME..."
10170     BEEP
10175     WAIT 2
10180 END IF
10185 RETURN
10190 !
10195 ! ======================================================================
10200 ! QK
10205 ! =======================================================================
10210 Qk:!
10215  PRINT CHR$(12)
10220  PRINT "THE PROGRAM GIVES A PLOT OF CHANNEL 1 VERSES TIME AS THE DEFAULT"
10225  PRINT "CASE WHEN THE PROGRAM IS FIRST RUN. IN ORDER TO SPEED UP THE"
10230  PRINT "PLOTTING , NOT ALL OF THE 7000 DATA POINTS ARE PLOTTED ON THE"
10235  PRINT "SCREEN. THE NUMBER OF POINTS PLOTTED DEPENDS ON THE TIME SPAN "
10240  PRINT "OF X-AXIS. FOR A SPAN OF LESS THAN 1.2 SEC EVERY DATA POINT IS"
10245  PRINT "PLOTTED. IF GREATER THAN 1.2 SEC. APPROXIMATELY 1200 POINTS ARE"
10250  PRINT "PLOTTED. THE DEFAULT TIME SPAN IS 7 SEC. FOR THE ACTUAL DATA AND"
10255  PRINT "3.5 SEC. FOR THE CALIBRATION DATA. THIS IS LIMITED BY THE BUFFER"
10260  PRINT "SIZE OF 7000 POINTS PER CHANNEL . SINCE THERE WERE ACTUALLY 8000"
10265  PRINT "DATA POINTS RECORDED DURING THE CALIBRATION OF THE BLADE, THE"
10270  PRINT "LAST 1000 POINTS ARE STORED IN THE CHANNEL WHICH IS 10 GREATER"
10275  PRINT "THEN THE FIRST ONE ,IF REQUIRED. THIS IS REFLECTED IN THE CHANNEL"
10280  PRINT "LISTING FOR THE CALIBRATION DATA."
10285  RETURN
10290 !
10295 ! ==============================================================
10300 !   QUICK LOOK
10305 ! ==============================================================
10310 Quick_look:   !
10315  GINIT
10320  GRAPHICS ON
10325  DEG
10330  LORG 5
10335  IF Time_plot THEN
10340     Xmin=0
10345     Xmax=7000
10350     IF Calib_data THEN Xmax=Xmax/2
10355     X_time_min=0
10360     X_time_max=Xmax/1000
10365  ELSE
10370     I_xmin=1
10375     Power_xmin=2
10380     Xmin=-100
10385     I_xmax=7
10390     Power_xmax=2
10395     Xmax=300
10400  END IF
10405  I_ymin=1
10410  Power_ymin=2
10415  Ymin=-100
10420  I_ymax=7
10425  Power_ymax=2
10430  Ymax=300
10435  GOSUB Channel_disp
10440  GOTO Plot_set_up
10445 !
10450 ! ==============================================================
10455 ! CHANNEL DISPLAY
10460 ! =============================================================
10465 Channel_disp:!
10470  Channel_disp_x=Channel_x
10475  Channel_disp_y=Channel_y
10480  IF Channel_x=35 THEN Channel_disp_x=Filter_channel
10485  IF Channel_y=35 THEN Channel_disp_y=Filter_channel
10490  RETURN
10495 !
10500 ! ======================================================================
10505 ! TYP
10510 ! ======================================================================
10515 Typ:!
10520  PRINT CHR$(12)
10525  PRINT "THE 'X-Y' SOFT KEY CHANGES THE PROGRAM FROM THE PLOTTING OF A"
```

```
10530  PRINT "SINGLE CHANNEL VERSES TIME ,TO THE X VERSES Y MODE ,OR BACK TO"
10535  PRINT "THE CHANNEL VERSES TIME MODE ,EACH TIME IT IS PRESSED. THE"
10540  PRINT "CHANGE IS ACCOMPANIED BY A BEEP. ONCE A PLOTTING MODE IS ENTERED,"
10545  PRINT "ALL PLOTS ARE IN THAT MODE UNTIL THE 'X-Y' SOFT KEY IS PRESSED"
10550  PRINT "AGAIN"
10555  RETURN
10560     !
10565 ! ====================================================================
10570 ! PLOT TYPE
10575 ! ====================================================================
10580 Plot_type: !
10585  Time_plot=NOT Time_plot
10590  BEEP
10595  RETURN
10600 !
10605 ! ====================================================================
10610 ! SEL
10615 ! ====================================================================
10620 Sel:!
10625  PRINT CHR$(12)
10630  PRINT "THE 'SELECT' SOFT KEY IS USED TO CHOOSE THE NEXT CHANNEL NUMBER"
10635  PRINT "TO BE PLOTTED ON THE PRESENT PLOT. THE NEW DATA IS PLOTTED"
10640  PRINT "WITHOUT ERASING THE OLD PLOT. THEREFORE THE AXIS AND LABELING IS"
10645  PRINT "APPROPIATE FOR THE FIRST CHANNEL PLOTTED . ANY ATTEMPT TO CHANGE"
10650  PRINT "THE SCALES WILL RESULT IN ONLY THE LAST CHANNEL PLOTTED BEING"
10655  PRINT "DISPLAYED. IF YOU WANT TO VIEW TWO SEPARATE CHANNELS VERSES THE"
10660  PRINT "SAME X-AXIS ,YOU CAN USE THE 'SPLITVIEW' SOFT KEY , AND FOLLOW"
10665  PRINT "THE INSTRUCTIONS GIVEN"
10670  RETURN
10675  !
10680 ! ==========================================================
10685 !   SELECT CHANNEL
10690 ! ==========================================================
10695 Select_channel:   !
10700  IF Time_plot THEN
10705     INPUT "ENTER SIGNAL NUMBER TO BE PLOTTED VERSES TIME: ",Channel_y
10710     IF Channel_y>Total_channels OR Channel_y<1 THEN
10715        DISP "CHANNEL NUMBER OUTSIDE LIMITS ...TRY AGAIN"
10720        BEEP
10725        WAIT 1
10730        GOTO Select_channel
10735     END IF
10740  ELSE
10745     INPUT "ENTER SIGNAL NUMBER TO BE PLOTTED ON X-AXIS: ",Channel_x
10750     INPUT "ENTER SIGNAL NUMBER TO BE PLOTTED ON Y-AXIS: ",Channel_y
10755     IF Channel_x>Total_channels OR Channel_x<1 OR Channel_y>Total_channels
 OR Channel_y<1 THEN
10760        DISP "CHANNEL NUMBER OUTSIDE LIMITS ...TRY AGAIN"
10765        BEEP
10770        WAIT 1
10775        GOTO Select_channel
10780     END IF
10785  END IF
10790  GOSUB Channel_disp
10795  IF Channel_x>28 AND Channel_x<33 AND Channel_y>28 AND Channel_y<33 THEN
10800     IF Channel_y MOD 2=0 THEN Channel_y=Channel_y-1
10805     GOTO Plot_position
10810  ELSE
10815     IF Channel_y=33 OR Channel_x=33 THEN
10820        Channel_y=33
10825        GOTO Plot_fft
10830     ELSE
10835        GOTO Plot_engg
10840     END IF
10845  END IF
10850 !
```

```
10855 ! ======================================================================
10860 ! VW
10865 ! ======================================================================
10870 Vw:!
10875  PRINT CHR$(12)
10880  PRINT "THE 'VIEW' SOFT KEY IS USED TO PLOT ANY OF THE CHANNELS DESIRED"
10885  PRINT "THIS ERASES THE OLD PLOT AND GIVES A PLOT OF A SINGLE CHANNEL."
10890  PRINT "CHANNEL 33 CAN NOT BE PLOTTED VERSES ANOTHER CHANNEL, AND THERE-"
10895  PRINT "FORE THE PROGRAM PREVENTS YOU FROM DOING SO. THE PROBE CHANNELS"
10900  PRINT "ARE USED TO DERIVE THE X-Y DISPLACEMENT OF THE SHAFTING. THE"
10905  PRINT "CALCULATED X-Y DISPLACEMENT IS STORED IN CHANNELS 29,30,31,32 ,"
10910  PRINT "ANY ATTEMPT TO PLOT ONE OF THE CHANNELS NUMBERED 29-32 WILL"
10915  PRINT "RESULT IN THE SHAFT X-Y DISPLACEMENT BEING DISPLAYED IN A"
10920  PRINT "STANDARD OUTPUT FORMAT."
10925  RETURN
10930 !
10935 ! ============================================================
10940 !    NEW PLOT
10945 ! ============================================================
10950 New_plot:    !
10955  First_flag=0
10960  Split_flag=0
10965 New_plot_cont:!
10970  IF NOT Batch_mode THEN
10975     IF Time_plot THEN
10980        INPUT "ENTER SIGNAL NUMBER TO BE PLOTTED VERSES TIME:",Channel_y
10985        IF Channel_y<1 OR Channel_y>Total_channels THEN
10990           DISP "RE-";
10995           BEEP
11000           GOTO New_plot_cont
11005        END IF
11010     ELSE
11015        IF NOT Split_flag OR (Split_flag AND First_flag) THEN INPUT "ENTER
SIGNAL NUMBER TO BE PLOTTED ON X-AXIS: Channel_x",Channel_x
11020        INPUT "ENTER SIGNAL NUMBER TO BE PLOTTED ON Y-AXIS: Channel_y",Chan
nel_y
11025        IF Channel_x<1 OR Channel_x>Total_channels OR Channel_y<1 OR Channe
l_y>Total_channels THEN
11030           DISP "RE-";
11035           BEEP
11040           GOTO New_plot_cont
11045        END IF
11050        INPUT "ENTER START AND END TIMES: Plot_start_time,Plot_end_time or
CONT",Plot_start_time,Plot_end_time
11055     END IF
11060  END IF
11065  GOSUB Channel_disp
11070  IF Time_plot THEN
11075     IF Channel_y=33 THEN Fft_set_up
11080  ELSE
11085     IF Channel_y=33 OR Channel_x=33 THEN
11090        DISP "FFT MUST BE PLOTTED VERSES TIME. BUT I WILL LET YOU AWAY WITH
 IT"
11095        BEEP
11100        WAIT 2
11105        Channel_y=33
11110        GOTO Fft_set_up
11115     END IF
11120  END IF
11125 Input_x_range:    !
11130  IF Split_flag AND NOT First_flag THEN Input_y_range
11135  IF NOT Batch_mode THEN
11140     IF Time_plot THEN
11145        INPUT "ENTER TIMES (sec): X_time_min, X_time_max",X_time_min,X_time
_max
11150        IF X_time_min<0 OR X_time_max<0 OR X_time_min>Nscans/1000*Corr_fact
```

```
or OR X_time_max>2.5*Nscans/1000*Corr_factor THEN
11155           DISP "RE-";
11160           BEEP
11165           GOTO Input_x_range
11170        END IF
11175        IF ABS(X_time_min-X_time_max)<.001 THEN
11180           DISP "X-TIME SPAN IS <.001 RE-";
11185           BEEP
11190           GOTO Input_x_range
11195        END IF
11200        Xmin=1000*X_time_min
11205        Xmax=1000*X_time_max
11210     ELSE
11215        INPUT "ENTER: Xmin, Xmax",Xmin,Xmax
11220        IF ABS(Xmin-Xmax)<.001 THEN
11225           DISP "X-RANGE <.001 RE-";
11230           GOTO Input_x_range
11235        END IF
11240     END IF
11245  END IF
11250 Input_y_range:    !
11255  IF Time_plot AND Channel_y>28 AND Channel_y<33 THEN
11260     IF Channel_y MOD 2=0 THEN Channel_y=Channel_y-1
11265     GOTO Position_set_up
11270  END IF
11275  IF NOT Batch_mode THEN
11280     INPUT "ENTER: Ymin, Ymax: ",Ymin,Ymax
11285     PRINT CHR$(12)
11290     IF ABS(Ymin-Ymax)<.001 THEN
11295        DISP "Y-RANGE <.001 RE-";
11300        GOTO Input_y_range
11305     END IF
11310  END IF
11315    !
11320 Nice_x_scale:    !TO CHOOSE RATIONAL X SCALE
11325  IF NOT Time_plot THEN
11330     IF Xmin=0 THEN
11335        Power_xmin=0
11340        Mult_xmin=0
11345        Power_xmax=INT(LGT(ABS(Xmax)))
11350        Mult_xmax=ABS(Xmax/10^Power_xmax)
11355        GOTO Next_x_part_0
11360     END IF
11365     IF Xmax=0 THEN
11370        Power_xmax=0
11375        Mult_xmax=0
11380        Power_xmin=INT(LGT(ABS(Xmin)))
11385        Mult_xmin=ABS(Xmin/10^Power_xmin)
11390        GOTO Next_x_part_0
11395     END IF
11400     Power_xmax=INT(LGT(ABS(Xmax)))
11405     Mult_xmax=ABS(Xmax/10^Power_xmax)
11410     Power_xmin=INT(LGT(ABS(Xmin)))
11415     Mult_xmin=ABS(Xmin/10^Power_xmin)
11420 Next_x_part_0:              !
11425     FOR I=0 TO 14
11430        IF Mult_xmin<=Nice_scale(I) THEN Next_x_part_1
11435     NEXT I
11440 Next_x_part_1:              !
11445     IF Xmin>0 THEN
11450        I_xmin=I-1
11455     ELSE
11460        I_xmin=I
11465     END IF
11470     FOR I=0 TO 14
11475        IF Mult_xmax<=Nice_scale(I) THEN Next_x_part_2
```

```
11480      NEXT I
11485 Next_x_part_2:             !
11490      IF Xmax<0 THEN
11495         I_xmax=I-1
11500      ELSE
11505         I_xmax=I
11510      END IF
11515     !
11520      Xmin=Nice_scale(I_xmin)*10^Power_xmin*SGN(Xmin)
11525      Xmax=Nice_scale(I_xmax)*10^Power_xmax*SGN(Xmax)
11530      IF Xmin>0 AND Xmax>0 AND Xmin<.1*Xmax THEN
11535         Xmin=0
11540         GOTO Nice_x_scale
11545      END IF
11550      IF Xmin<0 AND Xmax>0 AND ABS(Xmin)<.1*Xmax THEN
11555         Xmin=-.1*Xmax
11560         GOTO Nice_x_scale
11565      END IF
11570      IF Xmin<0 AND Xmax<0 AND Xmax>.1*Xmin THEN
11575         Xmax=0
11580         GOTO Nice_x_scale
11585      END IF
11590  END IF
11595 Nice_y_scale:    !TO CHOOSE RATIONAL Y SCALE
11600  IF Ymin=0 THEN
11605     Power_ymin=0
11610     Mult_ymin=0
11615     Power_ymax=INT(LGT(ABS(Ymax)))
11620     Mult_ymax=ABS(Ymax/10^Power_ymax)
11625     GOTO Next_y_part_0
11630  END IF
11635  IF Ymax=0 THEN
11640     Power_ymax=0
11645     Mult_ymax=0
11650     Power_ymin=INT(LGT(ABS(Ymin)))
11655     Mult_ymin=ABS(Ymin/10^Power_ymin)
11660     GOTO Next_y_part_0
11665  END IF
11670  Power_ymax=INT(LGT(ABS(Ymax)))
11675  Mult_ymax=ABS(Ymax/10^Power_ymax)
11680  Power_ymin=INT(LGT(ABS(Ymin)))
11685  Mult_ymin=ABS(Ymin/10^Power_ymin)
11690 Next_y_part_0:             !
11695  FOR I=0 TO 14
11700     IF Mult_ymin<=Nice_scale(I) THEN Next_y_part_1
11705  NEXT I
11710 Next_y_part_1:             !
11715  IF Ymin>0 THEN
11720     I_ymin=I-1
11725  ELSE
11730     I_ymin=I
11735  END IF
11740  FOR I=0 TO 14
11745     IF Mult_ymax<=Nice_scale(I) THEN Next_y_part_2
11750  NEXT I
11755 Next_y_part_2:             !
11760  IF Ymax<0 THEN
11765     I_ymax=I-1
11770  ELSE
11775     I_ymax=I
11780  END IF
11785   !
11790  Ymin=Nice_scale(I_ymin)*10^Power_ymin*SGN(Ymin)
11795  Ymax=Nice_scale(I_ymax)*10^Power_ymax*SGN(Ymax)
11800  IF Ymin>0 AND Ymax>0 AND Ymin<.1*Ymax THEN
11805     Ymin=0
```

```
11810     GOTO Nice_y_scale
11815  END IF
11820  IF Ymin<0 AND Ymax>0 AND ABS(Ymin)<.1*Ymax THEN
11825     Ymin=-.1*Ymax
11830     GOTO Nice_y_scale
11835  END IF
11840  IF Ymin<0 AND Ymax<0 AND Ymax>.1*Ymin THEN
11845     Ymax=0
11850     GOTO Nice_y_scale
11855  END IF
11860  GOTO Plot_set_up
11865 !
11870 ! ========================================================================
11875 ! SP_VW
11880 ! ========================================================================
11885 Sp_vw:!
11890  PRINT CHR$(12)
11895  PRINT "THE 'SPLIT VIEW' SOFT KEY IS USED TO PLOT TWO GRAPHS ON THE"
11900  PRINT "SCREEN AT THE SAME TIME. EACH GRAPH IS HALF AS HIGH AS NORMAL."
11905  PRINT "THE X-AXIS MUST BE THE SAME FOR BOTH GRAPHS, BUT IT WORKS ON TIME"
11910  PRINT "PLOTS AND X VERSES Y PLOTS. THE FIRST GRAPH IS PLOTTED BY"
11915  PRINT "PRESSING THE 'SPLIT VIEW' SOFT KEY ,AND FOLLOWING INSTRUCTIONS."
11920  PRINT "THE SECOND GRAPH IS OBTAINED BY PRESSING THE 'SPLIT VIEW' SOFT"
11925  PRINT "KEY AGAIN. THE OTHER SOFT KEYS ,SUCH AS THE CURSOR OR MIN/MAX"
11930  PRINT "CHANGE KEYS ,WORK ON THE LAST CHANNEL PLOTTED."
11935  RETURN
11940 !
11945 ! ===============================================================
11950 !   TWO PLOT   SPLIT SCREEN ROUTINE
11955 ! ===============================================================
11960 !
11965 Two_plot:!
11970  Split_size=2.5                  !FOR USE IN "CSIZE Split_size"
11975  Split_flag=1
11980  Mask_word=1
11985  First_flag=NOT First_flag
11990  IF NOT First_flag THEN GSTORE Screen_buffer(*)
11995  GOTO New_plot_cont
12000 ! ===============================================================
12005 !   FFT SET-UP
12010 ! ===============================================================
12015 Fft_set_up:   !
12020  DEG
12025  CSIZE 3.5
12030  VIEWPORT 10,115,13,80
12035  Split_flag=0
12040  First_flag=0
12045  GCLEAR
12050  Max_frequency=200
12055  INPUT "ENTER MAXIMUM FREQUENCY TO BE PLOTTED: ",Max_frequency
12060  WINDOW 0,Max_frequency,0,100
12065  CLIP ON
12070  AXES Max_frequency/50,2,0,0,5,5
12075  CLIP OFF
12080  MOVE 0,-3
12085  LABEL "0"
12090  MOVE Max_frequency,-3
12095  LABEL VAL$(Max_frequency)
12100  MOVE Max_frequency/2,-5
12105  LABEL "FREQUENCY (hz)"
12110  MOVE Max_frequency/2,120
12115  LABEL Title$
12120  MOVE Max_frequency/2,115
12125  LABEL "FFT of "&Channel_desc$(Fft_no)
12130  Multiplier=1/Scale_factor(Fft_no)*Slope(Fft_no)
12135  Fft_units$=Units$(Fft_no)
```

```
12140  MOVE Max_frequency/2,110
12145  LABEL USING "21A,MD.DDE,7A";"MAXIMUM AMPLITUDE =  ",Amplitude*Multiplier,
Fft_units$
12150  MOVE Max_frequency/2,105
12155  LABEL USING "DDDD,25A,D.DD,2A";Nn," POINTS STARTING AT TIME ",INT((Fft_mi
n+1)*Corr_factor)/1000," s"
12160  LDIR 90
12165  MOVE -.05*Max_frequency,50
12170  LABEL "RELATIVE AMPLITUDE"
12175  MOVE -.03*Max_frequency,0
12180  LABEL "0%"
12185  MOVE -.03*Max_frequency,100
12190  LABEL "100%"
12195  CLIP ON
12200  LDIR 0
12205  GOTO Plot_fft
12210 !
12215 ! ============================================================
12220 !   POSITION SET-UP
12225 ! ============================================================
12230 Position_set_up:   !
12235  DEG
12240  GCLEAR
12245  Split_flag=0
12250  First_flag=0
12255  CSIZE 3.5
12260  VIEWPORT 10,115,8,85
12265  CLIP ON
12270  SHOW -.5,.5,-.5,.5
12275  AXES .02,.02,0,0,5,5
12280  MOVE SIN(0)*.35,COS(0)*.35
12285  FOR Angle=0 TO 360 STEP 3
12290     DRAW SIN(Angle)*.35,COS(Angle)*.35
12295  NEXT Angle
12300  LORG 4
12305  MOVE .5,0
12310  LABEL "STARBOARD"
12315  LORG 3
12320  MOVE .35,0
12325  LABEL "0.35 mm"
12330  LORG 1
12335  MOVE 0,.35
12340  LABEL "0.35 mm"
12345  LORG 4
12350  MOVE -.5,0
12355  LABEL "PORT"
12360  LORG 5
12365  MOVE .35,.45
12370  IF Channel_y=31 THEN LABEL "FORWARD PROBE LOCATION"
12375  IF Channel_y=29 THEN LABEL "AFT PROBE LOCATION"
12380  CLIP OFF
12385  MOVE 0,.625
12390  GOSUB Page_header
12395  LABEL "ANALYSIS DATE: "&Today$&"    TIME: "&Time_today$
12400  MOVE 0,.575
12405  IF LEN(Title$)>12 THEN
12410     LABEL Title$
12415     MOVE 0,.5025
12420     LABEL Dates$&"  "&Times$&"  FROM: "&VAL$(X_time_min)&" sec TO "&VAL$(X
_time_max)&" sec"
12425  ELSE
12430     LABEL Title$&"  "&Dates$&"  "&Times$&"  FROM: "&VAL$(X_time_min)&" sec
 TO "&VAL$(X_time_max)&" sec"
12435  END IF
12440  CLIP ON
12445  IF NOT Position_flag THEN GOSUB Rotation_calc
```

```
12450  GOTO Plot_position
12455 !
12460 ! =============================================================
12465 !    PLOT SET-UP
12470 ! =============================================================
12475 Plot_set_up:    !
12480  GCLEAR
12485  IF Split_flag AND NOT First_flag THEN GLOAD Screen_buffer(*)
12490  CLIP ON
12495  IF Time_plot THEN
12500     Xmin=X_time_min*1000
12505     Xmax=X_time_max*1000
12510  ELSE
12515     Xmin=Nice_scale(I_xmin)*10^Power_xmin*SGN(Xmin)
12520     Xmax=Nice_scale(I_xmax)*10^Power_xmax*SGN(Xmax)
12525     IF Xmin=Xmax AND NOT Batch_mode THEN
12530        DISP "Xmin=Xmax  SELECT ""VIEW"" AND TRY AGAIN"
12535        BEEP
12540        GOTO Main_sub_loop
12545     END IF
12550  END IF
12555  Ymin=Nice_scale(I_ymin)*10^Power_ymin*SGN(Ymin)
12560  Ymax=Nice_scale(I_ymax)*10^Power_ymax*SGN(Ymax)
12565  IF Ymin=Ymax AND NOT Batch_mode THEN
12570     DISP "Ymin=Ymax  SELECT ""VIEW"" AND TRY AGAIN"
12575     BEEP
12580     GOTO Main_sub_loop
12585  END IF
12590  CSIZE 3.5
12595  VIEWPORT 15,130,13,90
12600  IF Split_flag THEN
12605     CSIZE (Split_size)
12610     IF First_flag THEN
12615        VIEWPORT 15,130,52,90
12620     ELSE
12625        VIEWPORT 15,130,11,49
12630     END IF
12635  END IF
12640  FRAME
12645  WINDOW Xmin,Xmax,Ymin,Ymax
12650  X_scale=Xmax-Xmin
12655  Y_scale=Ymax-Ymin
12660  X_tick=100
12665  X_major=5
12670  IF X_scale<=1000 THEN
12675     X_tick=50
12680     X_major=4
12685  END IF
12690  IF X_scale<=500 THEN
12695     X_tick=25
12700     X_major=4
12705  END IF
12710  IF X_scale<=100 THEN
12715     X_tick=5
12720     X_major=4
12725  END IF
12730  IF X_scale<=50 THEN
12735     X_tick=2.5
12740     X_major=4
12745  END IF
12750  IF X_scale<=10 THEN
12755     X_tick=.5
12760     X_major=4
12765  END IF
12770  IF X_scale<=5 THEN
12775     X_tick=.25
```

```
12780      X_major=4
12785   END IF
12790   IF X_scale<=1 THEN
12795      X_tick=.02
12800      X_major=5
12805   END IF
12810   IF X_scale<=.5 THEN
12815      X_tick=.01
12820      X_major=5
12825   END IF
12830   Y_tick=100
12835   Y_major=5
12840   IF Y_scale<=1000 THEN
12845      Y_tick=50
12850      Y_major=4
12855   END IF
12860   IF Y_scale<=500 THEN
12865      Y_tick=25
12870      Y_major=4
12875   END IF
12880   IF Y_scale<=100 THEN
12885      Y_tick=5
12890      Y_major=5
12895   END IF
12900   IF Y_scale<=50 THEN
12905      Y_tick=2.5
12910      Y_major=4
12915   END IF
12920   IF Y_scale<=10 THEN
12925      Y_tick=.5
12930      Y_major=4
12935   END IF
12940   IF Y_scale<=5 THEN
12945      Y_tick=.25
12950      Y_major=4
12955   END IF
12960   IF Y_scale<=1 THEN
12965      Y_tick=.02
12970      Y_major=5
12975   END IF
12980   IF Y_scale<=.5 THEN
12985      Y_tick=.01
12990      Y_major=5
12995   END IF
13000   AXES X_tick,Y_tick,Xmin,Ymin,X_major,Y_major,3
13005   DISABLE
13010   LINE TYPE 3
13015   MOVE Xmin,0
13020   DRAW Xmax,0
13025   MOVE 0,Ymin
13030   DRAW 0,Ymax
13035   LINE TYPE 1
13040   ENABLE
13045   CLIP OFF
13050   LDIR 0
13055   IF Split_flag THEN
13060      IF First_flag THEN
13065         MOVE Xmin+.5*X_scale,Ymax+.075*Y_scale
13070         GOSUB Page_header
13075         LABEL "ANALYSIS DATE: "&Today$&"    TIME: "&Time_today$
13080         MOVE Xmin+.5*X_scale,Ymax+.025*Y_scale
13085         IF Time_plot THEN
13090            IF LEN(Title$)>35 THEN
13095               LABEL Title$
13100               MOVE Xmin+.5*X_scale,Ymax-.025*Y_scale
13105               LABEL Dates$&"  "&Times$
```

```
13110              ELSE
13115                 LABEL Title$&"  "&Dates$&"  "&Times$
13120              END IF
13125           ELSE
13130              IF LEN(Title$)>12 THEN
13135                 LABEL Title$
13140                 MOVE Xmin+.5*X_scale,Ymax-.025*Y_scale
13145                 LABEL Dates$&"  "&Times$&"  FROM: "&VAL$(Plot_start_time)&" s
ec TO "&VAL$(Plot_end_time)&" sec"
13150              ELSE
13155                 LABEL Title$&"  "&Dates$&"  "&Times$&"  FROM: "&VAL$(Plot_sta
rt_time)&" sec TO "&VAL$(Plot_end_time)&" sec"
13160              END IF
13165           END IF
13170        ELSE
13175           MOVE Xmin+.5*X_scale,Ymin-.10*Y_scale
13180           IF Time_plot THEN
13185              LABEL "TIME (seconds)"
13190           ELSE
13195              IF Channel_x=35 THEN
13200                 LABEL "FILTERED "&Channel_desc$(Filter_channel)&Units$(Filter
_channel)
13205              ELSE
13210                 LABEL Channel_desc$(Channel_x)&Units$(Channel_x)
13215              END IF
13220           END IF
13225        END IF
13230     ELSE
13235        MOVE Xmin+.5*X_scale,Ymax+.06*Y_scale
13240        GOSUB Page_header
13245        LABEL "ANALYSIS DATE: "&Today$&"    TIME: "&Time_today$
13250        MOVE Xmin+.5*X_scale,Ymin-.10*Y_scale
13255        IF Time_plot THEN
13260           LABEL "TIME (seconds)"
13265        ELSE
13270           IF Channel_x=35 THEN
13275              LABEL "FILTERED "&Channel_desc$(Filter_channel)&Units$(Filter_ch
annel)
13280           ELSE
13285              LABEL Channel_desc$(Channel_x)&Units$(Channel_x)
13290           END IF
13295        END IF
13300        MOVE Xmin+.5*X_scale,Ymax+.025*Y_scale
13305        IF Time_plot THEN
13310           IF LEN(Title$)>35 THEN
13315              LABEL Title$
13320              MOVE Xmin+.5*X_scale,Ymax-.025*Y_scale
13325              LABEL Dates$&"  "&Times$
13330           ELSE
13335              LABEL Title$&"  "&Dates$&"  "&Times$
13340           END IF
13345        ELSE
13350           IF LEN(Title$)>12 THEN
13355              LABEL Title$
13360              MOVE Xmin+.5*X_scale,Ymax-.025*Y_scale
13365              LABEL Dates$&"  "&Times$&"  FROM: "&VAL$(Plot_start_time)&" sec
TO "&VAL$(Plot_end_time)&" sec"
13370           ELSE
13375              LABEL Title$&"  "&Dates$&"  "&Times$&"  FROM: "&VAL$(Plot_start_
time)&" sec TO "&VAL$(Plot_end_time)&" sec"
13380           END IF
13385        END IF
13390     END IF
13395     Label_increment=X_tick*X_major*2
13400     IF X_scale<=1000 THEN Label_increment=X_tick*X_major
13405     IF Time_plot THEN
```

```
13410      LORG 5
13415      FOR I=Xmin TO Xmax STEP Label_increment
13420         MOVE I,Ymin-.05*Y_scale
13425         LABEL I/1000
13430      NEXT I
13435   ELSE
13440      LORG 8
13445      FOR New_counter=Xmin TO Xmax STEP Label_increment
13450         IF ABS(New_counter)<.0001 THEN New_counter=0
13455         New_counter$[1,5]=VAL$(New_counter)
13460         IF POS(New_counter$,".")=0 THEN
13465            Start_pos=6-LEN(VAL$(INT(New_counter)))
13470         ELSE
13475            IF POS(New_counter$,".")=LEN(VAL$(New_counter))-1 THEN
13480               Start_pos=5-POS(New_counter$,".")
13485            ELSE
13490               Start_pos=4-POS(New_counter$,".")
13495            END IF
13500         END IF
13505         Start_pos=MAX(1,Start_pos)
13510         New_counter$[1,5]="     "
13515         New_counter$[Start_pos,5]=VAL$(New_counter)
13520         MOVE New_counter,Ymin-.05*Y_scale
13525         LABEL New_counter$
13530      NEXT New_counter
13535   END IF
13540   LORG 8
13545   Label_increment=Y_tick*Y_major*2
13550   IF Y_scale<=1000 THEN Label_increment=Y_tick*Y_major
13555   FOR New_counter=Ymin TO Ymax STEP Label_increment
13560      IF ABS(New_counter)<.0001 THEN New_counter=0
13565      New_counter$[1,5]=VAL$(New_counter)
13570      IF POS(New_counter$,".")=0 THEN
13575         Start_pos=6-LEN(VAL$(INT(New_counter)))
13580      ELSE
13585         IF POS(New_counter$,".")=LEN(VAL$(New_counter))-1 THEN
13590            Start_pos=5-POS(New_counter$,".")
13595         ELSE
13600            Start_pos=4-POS(New_counter$,".")
13605         END IF
13610      END IF
13615      Start_pos=MAX(1,Start_pos)
13620      New_counter$[1,5]="     "
13625      New_counter$[Start_pos,5]=VAL$(New_counter)
13630      MOVE Xmin-.005*X_scale,New_counter
13635      LABEL New_counter$
13640   NEXT New_counter
13645   LORG 5
13650   LDIR 90
13655   MOVE Xmin-.09*X_scale,Ymin+.5*Y_scale
13660   IF Channel_y=35 THEN
13665      LABEL "FILTERED "&Channel_desc$(Filter_channel)&Units$(Filter_channel)
13670   ELSE
13675      LABEL Channel_desc$(Channel_y)&Units$(Channel_y)
13680   END IF
13685   CLIP ON
13690   LDIR 0
13695   CSIZE 3.5
13700   GOTO Plot_engg
13705 !
13710 ! ================================================================
13715 !    PLOT ENGG UNITS
13720 ! ================================================================
13725 Plot_engg:    !
13730   PEN 1
13735   IF Time_plot THEN
```

```
14015 Plot_fft:    !
14020  PEN 1
14025  MOVE 0,Signals(33,Fft_min+1)/Scale_factor(33)
14030  FOR I=Fft_min+1 TO Fft_min+1+INT(.5+(Max_frequency*Nn)/(Scan_rate))
14035     DRAW (I-Fft_min-1)*(Scan_rate/Nn),Signals(33,I)/Scale_factor(33)
14040  NEXT I
14045  MOVE 0,Signals(33,Fft_min+1)/Scale_factor(33)
14050  PEN 0
14055  LABEL "+"
14060  PEN 1
14065  Current_record=Fft_min+1
14070  GOTO Main_sub_loop
14075 !
14080 ! ======================================================================
14085 ! LBL UP
14090 ! ======================================================================
14095 Lbl_up:!
14100  PRINT CHR$(12)
14105  PRINT "THE 'LABEL UP' SOFT KEY LABLES THE PRESENT POSITION OF THE CURSOR"
14110  PRINT "WITH THE ENGINEERING VALUE OF THAT POINT. THE LABEL IS VERTICAL  "
14115  PRINT "ABOVE THE POINT CHOOSEN WITH THE CURSOR. THE ENGINEERING VALUE   "
14120  PRINT "LABLED IS THE SAME AS THE ONE DISPLAYED AT THE BOTTOM OF THE     "
14125  PRINT "SCREEN ; HOWEVER NOT ALL OF THE ENGINEERING DATA IS NECESSARLY   "
14130  PRINT "LABLED ON THE PLOT.                                              "
14135  GOSUB Lbl_warning
14140  RETURN
14145 !
14150 ! ============================================================
14155 !   LABEL UP
14160 ! ============================================================
14165 Label_up:    !
14170  LORG 2
14175  LDIR 90
14180  Space1$="-"
14185  Space2$=" "
14190  GOSUB Label_this
14195  LDIR 0
14200  LORG 5
14205  RETURN
14210 !
14215 ! ============================================================
14220 !   LABEL THIS
14225 ! ============================================================
14230 Label_this:    !
14235  IF Channel_y=33 THEN
14240     MOVE Current_value*Scan_rate/Nn,Signals(33,Fft_min+1+Current_value)/Sc
ale_factor(33)
14245     LABEL USING ",K,5A,3A,K";Space1$,VAL$(Current_value*Scan_rate/Nn);" Hz
",Space2$
14250  ELSE
14255     IF Time_plot THEN
14260        IF Split_flag THEN CSIZE (Split_size)
14265        Signal_temp=Signals(Channel_y,Current_record)/Scale_factor(Channel_
disp_y)*Slope(Channel_disp_y)+Offset(Channel_disp_y)
14270        MOVE Current_record*Corr_factor,Signal_temp
14275        LABEL USING "A,5A,A";Space1$,VAL$(Signal_temp),Space2$
14280     ELSE
14285        IF Split_flag THEN CSIZE (Split_size)
14290        Disp_x=Signals(Channel_x,Current_record)/Scale_factor(Channel_disp_
x)*Slope(Channel_disp_x)+Offset(Channel_disp_x)
14295        Disp_y=Signals(Channel_y,Current_record)/Scale_factor(Channel_disp_
y)*Slope(Channel_disp_y)+Offset(Channel_disp_y)
14300        MOVE Disp_x,Disp_y
14305        LABEL USING "A,5A,X,5A,A";Space1$,VAL$(Disp_x),VAL$(Disp_y),Space2$
14310     END IF
14315  END IF
```

```
13740      MOVE Xmin+1,Signals(Channel_y,INT((Xmin+1)/Corr_factor))/Scale_factor(
Channel_disp_y)*Slope(Channel_disp_y)+Offset(Channel_disp_y)
13745      Step_size=MAX(1,INT(X_scale/1200))
13750      FOR I=MAX(1,INT((Xmin+1)/Corr_factor)) TO MIN(INT(Xmax/Corr_factor),Ns
cans) STEP Step_size
13755         DRAW I*Corr_factor,Signals(Channel_y,I)/Scale_factor(Channel_disp_y
)*Slope(Channel_disp_y)+Offset(Channel_disp_y)
13760      NEXT I
13765      MOVE (Xmin+1),Signals(Channel_y,INT((Xmin+1)/Corr_factor))/Scale_facto
r(Channel_disp_y)*Slope(Channel_disp_y)+Offset(Channel_disp_y)
13770      Current_record=Xmin+1
13775  ELSE
13780      Start_record=MAX(1,INT(Plot_start_time*Scan_rate+.5))
13785      Stop_record=MIN(Nscans,INT(Plot_end_time*Scan_rate+.5))
13790      Disp_x_start=Signals(Channel_x,Start_record)/Scale_factor(Channel_disp
_x)*Slope(Channel_disp_x)+Offset(Channel_disp_x)
13795      Disp_y_start=Signals(Channel_y,Start_record)/Scale_factor(Channel_disp
_y)*Slope(Channel_disp_y)+Offset(Channel_disp_y)
13800      MOVE Disp_x_start,Disp_y_start
13805      FOR I=Start_record+1 TO Stop_record
13810         Disp_x=Signals(Channel_x,I)/Scale_factor(Channel_disp_x)*Slope(Chan
nel_disp_x)+Offset(Channel_disp_x)
13815         Disp_y=Signals(Channel_y,I)/Scale_factor(Channel_disp_y)*Slope(Chan
nel_disp_y)+Offset(Channel_disp_y)
13820         DRAW Disp_x,Disp_y
13825      NEXT I
13830      MOVE Disp_x_start,Disp_y_start
13835      Current_record=Start_record
13840  END IF
13845  PEN 0
13850  LABEL "+"
13855  PEN 1
13860  IF Batch_mode THEN
13865     RETURN
13870  ELSE
13875     GOTO Main_loop
13880  END IF
13885 !
13890 ! ============================================================
13895 !    PLOT POSITION
13900 ! ============================================================
13905 Plot_position:    !
13910  Wait_time=0
13915  INPUT "ENTER: WAIT TIME BETWEEN PLOT UPDATES (seconds) or CONT",Wait_time
13920  PEN 1
13925  Start_index=MAX(INT((Xmin+1)/Corr_factor+.5),1)
13930  Stop_index=MIN(INT((Xmax+1)/Corr_factor+.5),Nscans)
13935  MOVE Signals(Channel_y,Start_index)/Scale_factor(29),Signals(Channel_y+1,
Start_index)/Scale_factor(29)
13940  Step_size=MAX(1,INT(X_scale/1200))
13945  FOR I=Start_index TO Stop_index STEP Step_size
13950     DRAW Signals(Channel_y,I)/Scale_factor(29),Signals(Channel_y+1,I)/Scal
e_factor(29)
13955     WAIT Wait_time
13960  NEXT I
13965  MOVE Signals(Channel_y,Start_index)/Scale_factor(29),Signals(Channel_y+1,
Start_index)/Scale_factor(29)
13970  PEN 0
13975  LABEL "+"
13980  PEN 1
13985  Current_record=Start_index
13990  GOTO Main_sub_loop
13995 !
14000 ! ============================================================
14005 !    PLOT FFT
14010 ! ============================================================
14320  CSIZE 3.5
14325  RETURN
14330 !
14335 ! ==========================================================================
14340 ! LBL DN
14345 ! ==========================================================================
14350 Lbl_dn:!
14355  PRINT CHR$(12)
14360  PRINT "THE 'LABEL DN' SOFT KEY LABLES THE PRESENT POSITION OF THE CURSOR"
14365  PRINT "WITH THE ENGINEERING VALUE OF THAT POINT. THE LABEL IS VERTICAL  "
14370  PRINT "BELOW THE POINT CHOOSEN WITH THE CURSOR. THE ENGINEERING VALUE   "
14375  PRINT "LABLED IS THE SAME AS THE ONE DISPLAYED AT THE BOTTOM OF THE     "
14380  PRINT "SCREEN ; HOWEVER NOT ALL OF THE ENGINEERING DATA IS NECESSARLY   "
14385  PRINT "LABLED ON THE PLOT.                                              "
14390  GOSUB Lbl_warning
14395  RETURN
14400 !
14405 ! ==========================================================================
14410 ! LBL WARNING
14415 ! ==========================================================================
14420 Lbl_warning:!
14425  PRINT "USE OF ; XMAXINC , XMAXDEC , XMININ , XMINDEC , YMAXINC , YMAXDEC"
14430  PRINT "YMININC ,or YMINDEC WILL NOT PRESERVE ANY LABLES WRITTEN BY"
14435  PRINT "'LABEL UP/DOWN' SOFT KEYS"
14440  RETURN
14445 ! ================================================================
14450 !   LABEL DOWN
14455 ! ================================================================
14460 Label_down:   !
14465  LORG 8
14470  LDIR 90
14475  Space1$=" "
14480  Space2$="-"
14485  GOSUB Label_this
14490  LDIR 0
14495  LORG 5
14500  RETURN
14505 !
14510 ! ================================================================
14515 !   ROTATION CALCULATE
14520 ! ================================================================
14525 Rotation_calc:   !
14530  DEG
14535  DISP "CALCULATING THE POSITION OF THE SHAFT"
14540  Cose11=COS(Angle_11)*Scale_factor(29)*Slope(11)
14545  Sine11=SIN(Angle_11)*Scale_factor(29)*Slope(11)
14550  Cose12=COS(Angle_12)*Scale_factor(29)*Slope(12)
14555  Sine12=SIN(Angle_12)*Scale_factor(29)*Slope(12)
14560  Cose13=COS(Angle_13)*Scale_factor(29)*Slope(13)
14565  Sine13=SIN(Angle_13)*Scale_factor(29)*Slope(13)
14570  Cose14=COS(Angle_14)*Scale_factor(29)*Slope(14)
14575  Sine14=SIN(Angle_14)*Scale_factor(29)*Slope(14)
14580  Offset_29=Cose11*Offset(11)/Slope(11)+Cose12*Offset(12)/Slope(12)+.5
14585  Offset_30=Sine11*Offset(11)/Slope(11)+Sine12*Offset(12)/Slope(12)+.5
14590  Offset_31=Cose13*Offset(13)/Slope(13)+Cose14*Offset(14)/Slope(14)+.5
14595  Offset_32=Sine13*Offset(13)/Slope(13)+Sine14*Offset(14)/Slope(14)+.5
14600  FOR I=1 TO Nscans
14605     Signals(29,I)=INT(Cose11*Signals(11,I)+Cose12*Signals(12,I)+Offset_29)
14610     Signals(30,I)=INT(Sine11*Signals(11,I)+Sine12*Signals(12,I)+Offset_30)
14615     Signals(31,I)=INT(Cose13*Signals(13,I)+Cose14*Signals(14,I)+Offset_31)
14620     Signals(32,I)=INT(Sine13*Signals(13,I)+Sine14*Signals(14,I)+Offset_32)
14625  NEXT I
14630  DISP " "
14635  Position_flag=1
14640  RETURN
14645 !
```

```
      ============================================================
14650 ! ============================================================
14655 ! CALC
      ============================================================
14660 ! ============================================================
14665 Calc:!
14670  PRINT CHR$(12)
14675  PRINT "THE 'CALC' SOFT KEY IS USED TO CALCULATE THE -"
14680  PRINT
14685  PRINT " OUT OF PLANE BLADE BENDING MOMENT          CHANNEL # 19"
14690  PRINT " BLADE SPINDLE TORQUE                       CHANNEL # 20"
14695  PRINT " OUT OF PLANE BLADE FORCE                   CHANNEL # 21"
14700  PRINT " RADIAL LOCATION OF THE LOAD ,and:          CHANNEL # 22"
14705  PRINT " CIRCUMFERENTIAL LOCATION OF THE LOAD       CHANNEL # 23"
14710  PRINT
14715  PRINT "FROM THE BLADE DATA CHANNELS # 1-6 , DEPENDING ON THE 'A-MATRIX'"
14720  PRINT "SELECTED. A BASELINE SUBTRACTION OPTION IS AVAILABLE TO SUBTRACT"
14725  PRINT "A BASE LINE CHOOSEN BY THE USER. AN EXPLANATION OF THE BASE LINE"
14730  PRINT "SUBTRACTION IS GIVEN IN THE SOFT KEYS ASSOCIATED WITH THE"
14735  PRINT "SUBTRACTION ROUTINE."
14740  PRINT "THE CALCULATE FUNCTION IS ONLY PERFORMED ON THE TIME SPAN OF THE"
14745  PRINT "DATA CURRENTLY PLOTTED ON THE CRT WITH RESPECT TO TIME."
14750  PRINT "THE OUTPUT MAY BE VIEWED BY PLOTTING THE CHANNELS LISTED ABOVE."
14755  PRINT "THE LONGER THE TIME SPAN USED FOR THE CALCULATION , THE LONGER"
14760  PRINT "THE CALCULATION TAKES."
14765  RETURN
14770 !
14775 ! ====================================================
14780 !   CALCULATE THE FORCES FROM THE 'SIGNAL' MATRIX, WITH OPTIONALLY
14785 !     HYDRO-DYNAMIC OFFSET SUBTRACTED.
14790 ! ====================================================
14795 Calculate:   !
14800  Calculate_flag=1
14805  X_start=MAX(0,INT(Xmin/Corr_factor)-150)
14810  X_finish=MIN(Nscans,INT(Xmax/Corr_factor)+150)
14815  Y$=""
14820  IF NOT Batch_mode AND NOT Calib_data THEN INPUT "WOULD YOU LIKE TO SUBTRA
CT THE HYDRO-DYNAMIC EFFECT? (Y or N)",Y$
14825  IF UPC$(Y$[1,1])="Y" AND Channel_y>6 THEN
14830     DISP "YOU MUST VIEW CHANNEL 1 TO 6 TO SUBTRACT HYDRODYNAMIC PART OF SI
GNAL"
14835     BEEP
14840     RETURN
14845  END IF
14850  ALLOCATE REAL Fred(1:6,1:7000)
14855  ALLOCATE REAL F(X_start+1:X_finish,19:21)
14860  ALLOCATE REAL F_offset(19:21)
14865  ALLOCATE Sig_offset(1:6)
14870  ALLOCATE INTEGER Signal_shuffle(1:7000)
14875  GRAPHICS OFF
14880  FOR I=1 TO 6
14885     Sig_offset(I)=(Offset(I)/Slope(I))*Scale_factor(I)
14890  NEXT I
14895  DISP "SHUFFLING DATA"
14900  REDIM Signals(1:6,1:7000)
14905  MAT Fred= Signals
14910  IF UPC$(Y$[1,1])="Y" THEN
14915     GOSUB Hydrodynamic
14920     GRAPHICS OFF
14925     ALLOCATE INTEGER Another_array(1:6,1:7000)
14930     MAT Another_array= Signals
14935     REDIM Signals(1:7000,1:6)
14940     MAT Signals= TRN(Another_array)
14945     DEALLOCATE Another_array(*)
14950  ELSE
14955     REDIM Signals(1:7000,1:6)
14960     MAT Signals= TRN(Fred)
14965  END IF
```

```
14970  IF X_start<>0 OR X_finish<>7000 THEN
14975     FOR I=1 TO X_start
14980        Signal_shuffle(X_finish-X_start+I)=I
14985     NEXT I
14990     FOR I=X_start+1 TO X_finish
14995        Signal_shuffle(I-X_start)=I
15000     NEXT I
15005     FOR I=X_finish+1 TO 7000
15010        Signal_shuffle(I)=I
15015     NEXT I
15020     MAT REORDER Signals BY Signal_shuffle
15025     REDIM Signals(1:X_finish-X_start,1:6)
15030  END IF
15035  IF Test_number>298 THEN
15040     Proper_loc=5
15045  ELSE
15050     IF Test_number=7 THEN
15055        Proper_loc=2
15060     ELSE
15065        I=Test_number
15070        IF (I>44 AND I<50) OR (I>51 AND I<55) OR (I>55 AND I<65) OR (I>65 A
ND I<74) OR (I>76 AND I<97) OR (I>110 AND I<121) THEN
15075           Proper_loc=6
15080        ELSE
15085           Proper_loc=4
15090        END IF
15095     END IF
15100  END IF
15105  Loc=4
15110  IF NOT Batch_mode AND NOT Calib_data THEN
15115     PRINT RPT$(CHR$(10),35)
15120     PRINT "MATRIX 1  :ALL 6 CHANNELS ,ALL LOCATIONS, MANUAL DATA CASE 1 ON
LY"
15125     PRINT "MATRIX 2  :CHANNEL 6 DEAD, ALL LOCATIONS, MANUAL DATA CASE 1 ON
LY"
15130     PRINT "MATRIX 3  :CHANNEL 4 DEAD, ALL LOCATIONS, MANUAL DATA CASE 1 ON
LY"
15135     PRINT I$;"MATRIX 4  :ALL 6 CHANNELS, ALL LOCATIONS, ALL DATA";N$
15140     PRINT I$;"MATRIX 5  :CHANNEL 4 DEAD, ALL LOCATIONS, ALL DATA";N$
15145     PRINT I$;"MATRIX 6  :CHANNEL 2 DEAD, ALL LOCATIONS, ALL DATA";N$
15150     PRINT
15155     PRINT "FOR TESTS; 1-6 ; 8-44 ; 50-51 ; 55 ; 65 ; 74-76 ; 97-110 ,and;
121-298 USE 4"
15160     PRINT
15165     PRINT "FOR TEST # 7, USE MATRIX 2"
15170     PRINT
15175     PRINT "FOR TESTS; 45-49 ; 52-54 ; 56-64 ; 66-73 ; 77-96 ,and; 111 TO 1
20 USE 6"
15180     PRINT
15185     PRINT "FOR TESTS; 299-343 USE MATRIX 5"
15190 Try_mat_again: !
15195     INPUT "ENTER WHICH 'A' MATRIX YOU WOULD LIKE TO USE (1-6)",Loc
15200     IF Loc<1 OR Loc>6 THEN
15205        BEEP
15210        DISP "RE-";
15215        GOTO Try_mat_again
15220     END IF
15225     IF Loc<>Proper_loc THEN
15230        For_shure$=""
15235        INPUT "ARE YOU SHURE THAT YOU WANT TO USE THIS 'A' MATRIX: Y OR CON
T",For_shure$
15240        IF UPC$(For_shure$)<>"Y" THEN Try_mat_again
15245     END IF
15250     PRINT CHR$(12)
15255  ELSE
15260     IF Calib_data THEN
```

```
15265        Loc=4
15270     ELSE
15275        Loc=Proper_loc
15280     END IF
15285  END IF
15290  FOR I=1 TO 3
15295     FOR J=1 TO 6
15300        A(J,I)=A_matrix(Loc,I,J)
15305     NEXT J
15310  NEXT I
15315  DISP "CALCULATING FORCES"
15320  MAT F= Signals*A
15325  MAT F_offset= Sig_offset*A
15330  FOR I=19 TO 21
15335     F_offset(I)=F_offset(I)*Scale_factor(I)+.5
15340  NEXT I
15345  REDIM Signals(1:6,1:7000)
15350  MAT Signals= Fred
15355  REDIM Signals(1:35,1:7000)
15360  ON ERROR GOTO Integer_error
15365  FOR I=X_start+1 TO X_finish
15370     Signals(19,I)=INT(F(I,19)*Scale_factor(19)+F_offset(19))      ! BENDING
 MOMENT
15375     Signals(20,I)=INT(F(I,20)*Scale_factor(20)+F_offset(20))      ! SPINDLE
 TORQUE
15380     Signals(21,I)=INT(F(I,21)*Scale_factor(21)+F_offset(21))      ! FORCE
15385     IF F(I,21)=0 THEN Next_point
15390     Temp_pos=(F(I,19)/F(I,21)*Scale_factor(22)+.5)    ! HEIGHT ABOVE BLADE
                                                              FOOT IN M
15395     IF ABS(Temp_pos)<32677 THEN Signals(22,I)=INT(Temp_pos)
15400     Temp_pos=-1*(F(I,20)/F(I,21)*Scale_factor(23)+.5)    ! DISTANCE FROM
 CENTERLINE IN m. (-ve SIGN TO TAKE INTO ACCOUNT SENSE OF TORQUE), L.E. is POS
15405     IF ABS(Temp_pos)<32677 THEN Signals(23,I)=INT(Temp_pos)
15410 Next_point:         !
15415  NEXT I
15420 Skip_calc: !
15425  OFF ERROR
15430  GRAPHICS ON
15435  DISP "FINISHED CALCULATING FORCES"
15440  BEEP
15445  DEALLOCATE Signal_shuffle(*)
15450  DEALLOCATE Sig_offset(*)
15455  DEALLOCATE F_offset(*)
15460  DEALLOCATE F(*)
15465  DEALLOCATE Fred(*)
15470  RETURN
15475 !
15480 Integer_error: !
15485  IF ERRN=20 THEN
15490     PRINT ERRM$;" OCCURED WHILE DOING CALCULATIONS FOR TEST # ";Test_numbe
r
15495  ELSE
15500     PRINT "UNEXPECTED ERROR ";ERRM$;" WHILE DOING CALCULATIONS FOR TEST NU
MBER ";Test_number
15505  END IF
15510  Same_data=1
15515  GOTO Skip_calc
15520  !
15525 ! =====================================================================
15530 ! HYDRO HELP
15535 ! =====================================================================
15540 Hydro_help:!
15545  GRAPHICS OFF
15550  Hard_copy=0
15555  PRINTER IS 1
15560  PRINT CHR$(12)
```

```
15565  PRINT "THE BASELINE WHICH IS SUBTRATED FROM THE SIGNAL IS DEFINED BY THE"
15570  PRINT "USER AS FOLLOWS: THE CURSOR IS MOVED ALONG TO THE BEGINNING OF   "
15575  PRINT "THE SECTION TO BE USED AS THE STARTING POINT FOR THE BASELINE.   "
15580  PRINT "THE 'SELECT POINT' SOFT KEY IS PRESSED TO CHOOSE THE BEGINNING OF"
15585  PRINT "THE SETION TO BE AVERAGED. THE CURSOR IS MOVED ALONG TO THE END  "
15590  PRINT "OF THE FIRST SECTION TO BE AVERAGED AND THE 'SELECT POINT' KEY IS"
15595  PRINT "PRESSED AGAIN. THIS SECTION IS AVERAGED TO GET THE STARTING POINT"
15600  PRINT "OF THE BASELINE. THE PROCEDURE IS REPEATED TO GET THE END POINT  "
15605  PRINT "OF THE BASELINE. THE PROCEDURE CAN BE REPEADED AS OFTEN AS       "
15610  PRINT "DESIRED TO DEFINE POINTS WHICH ARE THE AVERAGE VALUES OF THE     "
15615  PRINT "POINTS CONTAINED WITHIN THE BRACKETS. THE BASELINE CONSISTS OF   "
15620  PRINT "THESE AVERAGE POINTS JOINED BY STRAIGHT LINES. SIMILAR BASE LINES"
15625  PRINT "ARE CALCULATED FOR THE OTHER 5 CHANNELS USED AUTOMATICALLY. ANY  "
15630  PRINT "ONE OF THE CHANNELS #1-6 MAY BE USED TO CHOOSE THE TIMES OF THE  "
15635  PRINT "POINTS TO BE AVERAGED. PRESS'EXIT' WHEN FINISHED.                "
15640  PRINT "................................................................."
15645  PRINT "....................PRESS CONT ...................................."
15650  PAUSE
15655  PRINT CHR$(12)
15660  GRAPHICS ON
15665  RETURN
15670 ! ============================================================
15675 !    HYDRODYNAMIC CORRECTION
15680 ! ============================================================
15685 Hydrodynamic:    !
15690  GRAPHICS ON
15695  OFF KEY
15700  ON KEY 0 LABEL "SELECT POINT",3 GOSUB Get_point
15705  ON KEY 1 LABEL " " GOSUB Idle
15710  ON KEY 2 LABEL "HELP",3 GOSUB Hydro_help
15715  ON KEY 3 LABEL " " GOSUB Idle
15720  ON KEY 4 LABEL "EXIT",3 GOSUB Hydro_exit
15725  ON KEY 5 LABEL " " GOSUB Idle
15730  ON KEY 6 LABEL " " GOSUB Idle
15735  ON KEY 7 LABEL " " GOSUB Idle
15740  ON KEY 8 LABEL " " GOSUB Idle
15745  ON KEY 9 LABEL " " GOSUB Idle
15750  Xa=0
15755  Xb=0
15760  X1=0
15765  X2=0
15770  First_time=1
15775  Hydro_exit=0
15780  BEEP
15785 Hydro_loop:       !
15790  DISP "SELECT KEY FOR HYDRO-DYNAMIC CORRECTION "
15795  DISABLE
15800  IF Xa<>0 THEN GOSUB Mean_calculate
15805  ENABLE
15810  IF NOT Hydro_exit THEN Hydro_loop
15815  DISABLE
15820  GOSUB Hydro_calculate
15825  ENABLE
15830  GOSUB Main_keys
15835  RETURN
15840 !
15845 ! ============================================================
15850 !    IDLE
15855 ! ============================================================
15860 Idle:RETURN
15865 !
15870 ! ============================================================
15875 !    HYDRO EXIT
15880 ! ============================================================
15885 Hydro_exit:    !
15890  IF NOT First_time AND Xb=0 THEN Hydro_exit=1
```

```
15895  IF NOT Hydro_exit THEN BEEP
15900  RETURN
15905 !
15910 ! ============================================================
15915 !    GET POINT
15920 ! ============================================================
15925 Get_point:    !
15930  Xa=Xb
15935  Xb=Current_record
15940  MOVE Current_record*Corr_factor,Signals(Channel_y,Current_record)/Scale_f
actor(Channel_y)*Slope(Channel_y)+Offset(Channel_y)-.05*Y_scale
15945  IF Xa=0 THEN LABEL CHR$(91)
15950  IF Xa<>0 THEN LABEL CHR$(93)
15955  RETURN
15960 !
15965 ! ============================================================
15970 !    MEAN CALCULATE
15975 ! ============================================================
15980 Mean_calculate:    !
15985  DISP "CALCULATING MEAN HYDRO-DYNAMIC OFFSET"
15990  FOR J=1 TO 6
15995     Total=0
16000     FOR I=Xa TO Xb
16005        Total=Total+Signals(J,I)
16010     NEXT I
16015     Mean(1,J)=Mean(2,J)
16020     Mean(2,J)=Total/(Xb-Xa+1)
16025  NEXT J
16030  X1=X2
16035  X2=INT((Xa+Xb)/2)
16040  Xa=0
16045  Xb=0
16050  IF X1<>0 THEN GOSUB Hydro_calculate
16055  RETURN
16060 !
16065 ! ============================================================
16070 !    HYDRO CALCULATE
16075 ! ============================================================
16080 Hydro_calculate:    !
16085  DISP "CALCULATING HYDRO-DYNAMIC OFFSETS"
16090  Start=X1
16095  Finish=X2
16100  IF First_time THEN Start=X_start
16105  IF Hydro_exit THEN Finish=X_finish
16110  IF Hydro_exit THEN Start=X2
16115  FOR J=1 TO 6
16120     Mean_slope=(Mean(2,J)-Mean(1,J))/(X2-X1)
16125     FOR I=Start+1 TO Finish
16130        Signals(J,I)=Signals(J,I)-(I-X1)*Mean_slope-Mean(1,J)
16135     NEXT I
16140  NEXT J
16145  First_time=0
16150  RETURN
16155 !
16160 ! ===================================================================
16165 ! DK
16170 ! ===================================================================
16175 Dk:!
16180  PRINT CHR$(12)
16185  PRINT "THE TEST DATA MAY BE READ FROM DISK OR THE BACK-UP MAGNETIC TAPES"
16190  PRINT "IN ADDITION TO THE TEST DATA THERE ARE ALSO DYNAMIC CALIBRATION"
16195  PRINT "DISKS WHICH HAVE BEEN CONVERTED OVER TO A FORMAT READABLE BY THIS"
16200  PRINT "PROGRAM . THE TITLE OF THE DATA ON THE TEST DISKS IS 'PROPDATA'."
16205  PRINT "THIS IS THE DEFAULT TITLE WHICH THE PROGRAM USES TO READ DISKS."
16210  PRINT "THE DISKS CONTAINING THE DYNAMIC CALIBRATIONS ARE TITLED :"
16215  PRINT "'DYNAMIC1' to 'DYNAMIC20' . THE TITLE OF THE CALIBRATION DISK"
```

```
16220  PRINT "MUST BE ENTERED IN ORDER FOR THE DATA TO BE READ."
16225  RETURN
16230  !
16235  ! ==================================================================
16240  ! READ CALIB DATA
16245  ! ==================================================================
16250 Read_calib_data: !
16255  INPUT "ENTER NAME OF CALIBRATION DATA FILE :",File$
16260  Calib_data=1
16265  GOTO Read_disk_file
16270 !
16275 ! ==========================================================
16280 !   READ DATA
16285 ! ==========================================================
16290 Read_data:    !
16295  File$="PROPDATA"
16300  Calib_data=0
16305 Read_disk_file: !
16310  Mainline_exit=1
16315  ALLOCATE INTEGER Signal_data(1:7000,1:18)
16320  INPUT "PUT DATA DISK INTO RIGHT HAND DRIVE ,CONTINUE",R$
16325  ASSIGN @Data_file TO File$
16330  ON ERROR GOTO Keep_going
16335  IF File$<>"PROPDATA" THEN
16340     ENTER @Data_file;Title$,Dates$,Times$,N_channels,Nscans,Scan_rate,Sign
al_data(*)
16345  ELSE
16350     ENTER @Data_file;Title$,Dates$,Times$,N_channels,Nscans,Scan_rate,Int_
data,Int_pointer,Signal_data(*)
16355  END IF
16360 Ok_keep_going: !
16365  OFF ERROR
16370  ASSIGN @Data_file TO *
16375  Title$=TRIM$(Title$)
16380  Corr_factor=1000/Scan_rate
16385  REDIM Signals(1:18,1:7000)
16390  MAT Signals= TRN(Signal_data)
16395  DEALLOCATE Signal_data(*)
16400  REDIM Signals(1:35,1:7000)
16405  IF NOT Calib_data THEN
16410     ON ERROR GOSUB Input_test_num
16415     Test_number=VAL(Title$[5,8])
16420     OFF ERROR
16425     IF Test_number=103 OR Test_number=147 THEN
16430        INPUT "ENTER PROPER TEST NUMBER :",Temporary
16435        IF LEN(Title$)<8 THEN Title$="TEST    "
16440        Title$[6,8]=VAL$(Temporary)
16445        Test_number=Temporary
16450     END IF
16455     Disc_number=Test_number
16460     GOSUB Check_nscans
16465  END IF
16470  GOSUB Recorded_ch_des
16475  IF Calib_data THEN
16480     GOSUB Fix_calib_gain
16485  ELSE
16490     GOSUB Fix_test_gain
16495  END IF
16500  RETURN
16505  !
16510 ! ================================================================
16515 ! CHECK_NSCANS
16520 ! ================================================================
16525 Check_nscans:!
16530  DISP "CHANGING NSCANS TO REMOVE BAD DATA AT END OF RECORD"
16535  IF Test_number>0 AND Test_number<6 THEN Nscans=4000
```

```
16540  IF Test_number=9 THEN Nscans=6999
16545  IF Test_number=12 THEN Nscans=6999
16550  IF Test_number=20 THEN Nscans=6724
16555  IF Test_number=22 THEN Nscans=6973
16560  IF Test_number=33 THEN Nscans=6714
16565  IF Test_number=35 THEN Nscans=6447
16570  IF Test_number=51 THEN Nscans=3920
16575  IF Test_number=57 THEN Nscans=6538
16580  IF Test_number=59 THEN Nscans=6575
16585  IF Test_number=62 THEN Nscans=6708
16590  IF Test_number=66 THEN Nscans=6577
16595  IF Test_number=67 THEN Nscans=6870
16600  IF Test_number=76 THEN Nscans=6450
16605  IF Test_number=84 THEN Nscans=6574
16610  IF Test_number=85 THEN Nscans=6575
16615  IF Test_number=97 THEN Nscans=6726
16620  IF Test_number=99 THEN Nscans=5765
16625  IF Test_number=110 THEN Nscans=6723
16630  IF Test_number=113 THEN Nscans=6982
16635  IF Test_number=114 THEN Nscans=6644
16640  IF Test_number=116 THEN Nscans=6433
16645  IF Test_number=118 THEN Nscans=6588
16650  IF Test_number=119 THEN Nscans=6450
16655  IF Test_number=120 THEN Nscans=5698
16660  IF Test_number=123 THEN Nscans=6715
16665  IF Test_number=133 THEN Nscans=6999
16670  IF Test_number=137 THEN Nscans=6866
16675  IF Test_number=143 THEN Nscans=6708
16680  IF Test_number=144 THEN Nscans=6869
16685  IF Test_number=146 THEN Nscans=6853
16690  IF Test_number=150 THEN Nscans=6850
16695  IF Test_number=158 THEN Nscans=6844
16700  IF Test_number=159 THEN Nscans=6710
16705  IF Test_number=165 THEN Nscans=6723
16710  IF Test_number=166 THEN Nscans=6977
16715  IF Test_number=168 AND Batch_mode AND Disc_requested=167 THEN Nscans=6852
16720  IF Test_number=168 AND NOT Batch_mode THEN Nscans=6852
16725  IF Test_number=170 THEN Nscans=6668
16730  IF Test_number=172 THEN Nscans=6998
16735  IF Test_number=188 THEN Nscans=6998
16740  IF Test_number=193 THEN Nscans=6564
16745  IF Test_number=201 THEN Nscans=6576
16750  IF Test_number=217 THEN Nscans=6999
16755  IF Test_number=219 THEN Nscans=6705
16760  IF Test_number=222 THEN Nscans=6999
16765  IF Test_number=229 THEN Nscans=6703
16770  IF Test_number=232 THEN Nscans=6439
16775  IF Test_number=237 THEN Nscans=6578
16780  IF Test_number=239 THEN Nscans=6575
16785  IF Test_number=244 THEN Nscans=6852
16790  IF Test_number=252 THEN Nscans=6849
16795  IF Test_number=257 THEN Nscans=6854
16800  IF Test_number=258 THEN Nscans=6824
16805  IF Test_number=263 THEN Nscans=6432
16810  IF Test_number=263 THEN Nscans=6435
16815  IF Test_number=274 THEN Nscans=6849
16820  IF Test_number=281 THEN Nscans=6000
16825  IF Test_number=282 THEN Nscans=6845
16830  IF Test_number=285 THEN Nscans=6437
16835  IF Test_number=287 THEN Nscans=6554
16840  IF Test_number=292 THEN Nscans=6570
16845  IF Test_number=298 THEN Nscans=6559
16850  IF Test_number=302 THEN Nscans=6981
16855  IF Test_number=305 THEN Nscans=6844
16860  IF Test_number=306 THEN Nscans=5687
16865  IF Test_number=313 THEN Nscans=6987
```

```
16870  IF Test_number=316 THEN Nscans=6990
16875  IF Test_number=320 THEN Nscans=6841
16880  IF Test_number=329 THEN Nscans=5446
16085  IF Test_number=322 THEN Nscans=6589
16890  IF Test_number=335 THEN Nscans=6577
16895  IF Test_number=343 THEN Nscans=2457
16900  DISP "FOR TEST # ";Test_number;" THE NUMBER OF GOOD DATA POINTS = ";Nscan
s
16905  RETURN
16910                 !
16915 ! ======================================================================
16920 ! KEEP GOING
16925 ! ======================================================================
16930 Keep_going:!
16935  Do_you_realy$=""
16940  PRINT ERRM$
16945  BEEP
16950  IF ERRN=80 THEN
16955     INPUT "AN ERROR HAS OCCURED, DO YOU WANT TO CONTINUE : Y or CONT",Do_y
ou_realy$
16960     IF UPC$(Do_you_realy$)="Y" THEN
16965        GOTO Ok_keep_going
16970     ELSE
16975        GOTO The_end
16980     END IF
16985  ELSE
16990     GOTO The_end
16995  END IF
17000                 !
17005 ! ======================================================================
17010 ! INPUT TEST NUMBER
17015 ! ======================================================================
17020 Input_test_num:!
17025  BEEP
17030  IF ERRN=32 OR ERRN=10 THEN
17035     IF Batch_mode THEN
17040        PRINT " THE TEST # FOR DISC_REQUESTED ";Disc_requested;" HAD TO BE
FIXED"
17045        Temporary=Disc_requested
17050     ELSE
17055        INPUT "ENTER THE TEST #",Temporary
17060     END IF
17065     IF LEN(Title$)<8 OR Title$[1,4]<>"TEST" THEN Title$="TEST    "
17070     Title$[6,8]=VAL$(Temporary)
17075     Test_number=Temporary
17080  ELSE
17085     PRINT CHR$(129);ERRM$;CHR$(128)
17090     GOTO The_end
17095  END IF
17100  RETURN
17105 !
17110 ! ======================================================================
17115 ! MG TP
17120 ! ======================================================================
17125 Mg_tp:!
17130  PRINT CHR$(12)
17135  PRINT "THE TEST DATA IS BACKED UP ON 9-TRACK MAGNETIC TAPES , AT"
17140  PRINT "1600 BPI . THE TEST DATA MAY BE READ FROM THE DISKS OR THE MAG"
17145  PRINT "TAPE. TO READ THE MAG TAPE, THE APPROPIATE TAPE IS LOADED ON AN"
17150  PRINT "'INOVATIVE DATA TECHNOLOGY ' MODEL # GPIB1050 TAPE DRIVE AT 1600"
17155  PRINT "BPI . THE COMPUTER IS CONNECTED TO THE TAPE DRIVE VIA A HPIB"
17160  PRINT "IEEE-488 BUSS."
17165  PRINT "THE ADDRESSES REQUIRED ON THE TAPE DRIVE ARE: 716 FOR THE OUTPUT"
17170  PRINT "OF CONTROL CHARACTERS TO THE TAPE DRIVE ; AND 717 FOR THE DATA"
17175  PRINT "INPUT TO THE COMPUTER. THE INTERFACE CABLE MUST BE DAISY-CHAINED"
17180  PRINT "RATHER THAN PLACED IN PARALLEL AT THE BACK OF THE COMPUTER."
```

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17185  PRINT "THE PRINTER MUST BE CONNETED DIRECTLY TO THE COMPUTER , THE IDT"
17190  PRINT "TAPE DRIVE IS THEN CONNECTED TO THE PRINTER. IF THIS ARRANGEMENT"
17195  PRINT "IS NOT USED, THE PRINTER MAY LOCK-UP."
17200  RETURN
17205 !
17210 ! ============================================================
17215 !    READ MAGNETIC TAPE
17220 ! ============================================================
17225 Read_mag_tape:    !
17230  Calib_data=0
17235  Mainline_exit=1
17240  ALLOCATE INTEGER Signal_data(1:7000,1:18)
17245  REDIM Signals(1:7000,1:18)
17250  IF First_tape_read THEN
17255     INPUT "IS THE IDT TAPE DRIVE ON-LINE, 1600 BPI?",R$
17260     INPUT "ENTER THE DISC NUMBER YOU WANT TO READ",Disc_requested
17265     OUTPUT 716;"BS(4000)"
17270     First_tape_read=0
17275  END IF
17280  Space_ahead=1
17285  ASSIGN @Bufin TO BUFFER Signals(*)
17290 Read_more_tape:       !
17295  OUTPUT 716;"MF("&VAL$(Space_ahead)&")"
17300  DISP "SEARCHING FOR DISC: ";Disc_requested
17305  ASSIGN @Device TO 717
17310  CONTROL @Bufin,3;1,0,1
17315  ENTER @Device USING "80A,12A,12A";Title$,Dates$,Times$
17320  IF Title$[1,1]=CHR$(10) THEN End_of_data=1
17325  IF End_of_data THEN RETURN
17330  ENTER @Device;Disc_number,N_channels,Nscans,Scan_rate,Int_data,Int_pointe
r
17335  Space_ahead=Disc_requested-Disc_number
17340  IF Space_ahead<>0 THEN Read_more_tape
17345  OUTPUT 716;"MB(0)"
17350  TRANSFER @Device TO @Bufin;RECORDS 63,EOR (COUNT 4000,END),WAIT
17355  ASSIGN @Device TO *
17360  ASSIGN @Bufin TO *
17365  Title$=TRIM$(Title$)
17370  Corr_factor=1000/Scan_rate
17375  MAT Signal_data= Signals
17380  REDIM Signals(1:18,1:7000)
17385  MAT Signals= TRN(Signal_data)
17390  DEALLOCATE Signal_data(*)
17395  REDIM Signals(1:35,1:7000)
17400  ON ERROR GOSUB Input_test_num
17405  Test_number=VAL(Title$[5,8])
17410  OFF ERROR
17415  IF Disc_requested<>Test_number THEN
17420     IF Batch_mode THEN
17425        Temporary=Disc_requested
17430        PRINT "DISC REQUESTED = ";Disc_requested;" BUT TEST_NUMBER = ";Test
_number;" AND"
17435     ELSE
17440        BEEP
17445        DISP "DISC REQUESTED = ";Disc_requested;" BUT TEST # = ";Test_numbe
r;" ENTER TEST #";
17450        INPUT Temporary
17455        DISP ""
17460     END IF
17465     IF LEN(Title$)<8 THEN Title$="TEST    "
17470     Title$[6,8]=VAL$(Temporary)
17475     Test_number=Temporary
17480  END IF
17485  Disc_number=Test_number
17490  GOSUB Check_nscans
17495  GOSUB Recorded_ch_des
```

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17500  GOSUB Fix_test_gain
17505  RETURN
17510 !
17515 ! =============================================================
17520 !    RPM CALCULATE
17525 ! =============================================================
17530 Rpm_calculate:    !
17535  Any_rpm_pulse=1
17540  IF NOT Calib_data THEN
17545     DISP "CALCULATING RPM FROM SHAFT RATE PULSES"
17550     Rpm_ref=150            !REFERENCE LEVEL IN A/D COUNTS
17555     FOR I=1 TO Nscans
17560        IF Signals(Rpm_channel,I)<-Rpm_ref THEN First_found
17565     NEXT I
17570     Any_rpm_pulse=0
17575     DISP "NO RPM PULSES FOUND"
17580     WAIT 1
17585     BEEP
17590  END IF
17595  RETURN
17600     !
17605 First_found:       !
17610  IF I>1 THEN
17615     Rpm_pulse(0)=1
17620     Rpm_pulse(1)=I
17625  ELSE
17630     Rpm_pulse(0)=0
17635     Rpm_pulse(1)=1
17640  END IF
17645     !
17650 Pulse_loop:   !
17655  FOR J=2 TO 50
17660     FOR I=Rpm_pulse(J-1)+240 TO Rpm_pulse(J-1)+400
17665        IF I>Nscans THEN Last_pulse
17670        IF Signals(Rpm_channel,I)<-Rpm_ref THEN Pulse_found
17675     NEXT I
17680 Pulse_found:         !
17685     Rpm_pulse(J)=I
17690  NEXT J
17695 Last_pulse:      !
17700  Numb_of_pulse=J
17705  Rpm_pulse(J)=Nscans
17710  FOR J=2 TO Numb_of_pulse-1
17715     Rpm(J)=INT(60*Scale_factor(34)/((Rpm_pulse(J)-Rpm_pulse(J-1))/Scan_rat
e)+.5)
17720  NEXT J
17725     !
17730     !TRANSFFERING SHAFT SPEED DATA INTO SIGNALS-ARRAY
17735     !
17740  Rpm(1)=Rpm(2)
17745  FOR J=1 TO Numb_of_pulse
17750     FOR I=Rpm_pulse(J) TO Rpm_pulse(J+1)
17755        Signals(34,I)=Rpm(J)
17760     NEXT I
17765  NEXT J
17770  FOR I=1 TO Rpm_pulse(1)
17775     Signals(34,I)=Rpm(1)
17780  NEXT I
17785  DISP ""
17790  RETURN
17795 !
17800 ! =============================================================
17805 !    GET SPEED
17810 ! =============================================================
17815 Get_speed:   !
17820  FOR J=1 TO Numb_of_pulse
```

```
17825     IF Current_record<Rpm_pulse(J) THEN Speed_found
17830  NEXT J
17835 Speed_found:      !
17840  Shaft_speed=Rpm(J)
17845  RETURN
17850 !
17855 ! =======================================================================
17860 ! FIL
17865 ! =======================================================================
17870 Fil:!
17875  PRINT CHR$(12)
17880  PRINT "THE DIGITAL FILTER ROUTINE CAN BE USED TO FILTER THE CALCULATED"
17885  PRINT "FORCE QUANTITIES AND STORE THE FILTERED CALCULATED DATA IN"
17890  PRINT "OTHER CHANNELS AS FOLLOWS:"
17895  PRINT
17900  PRINT "CALCULATED QUANTITY     CH.#  TO   FILTERED QUANTITY        CH.#"
17905  PRINT "BENDING MOMENT           19   ==   BENDING MOMENT(FILTERED)  24"
17910  PRINT "SPINDLE TORQUE           20   ==   SPINDLE TORQUE(FILTERED)  25"
17915  PRINT "FORCE                    21   ==   FORCE(FILTERED)           26"
17920  PRINT
17925  PRINT "THE LOAD LOCATIONS ARE DETERMINED BY THE FOLLOWING METHOD:"
17930  PRINT "RADIAL LOC.(FILTERED) CH# 27 = CH#24 / CH#26"
17935  PRINT "CIRCUMFERENTIAL  LOC.(FILTERED) CH#28 = CH#25 / CH#26"
17940  PRINT
17945  PRINT "OR MAY BE USED TO FILTER ANY OF THE ACQUIRED CHANNELS AND STORE"
17950  PRINT "THE FILTERED RESULT IN CHANNEL # 35. THE FILTERING IS ONLY"
17955  PRINT "PERFORMED ON THE TIME DURATION OF THE DATA CURRENTLY PLOTTED ON"
17960  PRINT "THE SCREEN."
17965  RETURN
17970 !
17975 ! ==============================================================
17980 !    DIGITAL FILTER
17985 ! ==============================================================
17990 Digital_filter:   !
17995  INPUT "FILTER FORCES OR CHANNEL DATA? F or C",R$
18000  IF UPC$(R$[1,1])="C" THEN GOTO Signal_filter
18005  IF UPC$(R$[1,1])<>"F" THEN
18010     DISP "RE-";
18015     BEEP
18020     GOTO Digital_filter
18025  END IF
18030  IF NOT Filter_flag THEN GOSUB Filter_design
18035  GRAPHICS OFF
18040  ALLOCATE REAL Filter_temp(1:7000,19:21)
18045    !
18050    !   PRE FILTER
18055    !
18060  DISP "PERFORMING PRE-FILTERING OF DATA"
18065  Total_size=Pre_size*2+1
18070  ALLOCATE INTEGER B(1:Total_size)
18075  FOR I=1 TO Total_size-4
18080     B(I)=I+4
18085  NEXT I
18090  FOR I=1 TO 4
18095     B(I+Total_size-4)=I
18100  NEXT I
18105  ALLOCATE REAL H1(1:Total_size)
18110  ALLOCATE REAL H2(1:Total_size)
18115  ALLOCATE REAL H3(1:Total_size)
18120  X_filter_min=MAX(1,INT(X_time_min*1000/Corr_factor))
18125  Xmax=MIN(INT(X_time_max*1000/Corr_factor),Nscans)
18130  FOR I=1 TO Total_size
18135     Time_index=X_filter_min+1-Pre_size+I-1-4*(Post_size)
18140     IF (Time_index<=0) OR (Time_index>Nscans) THEN
18145        IF Time_index<=0 THEN
18150           H1(I)=Signals(19,1)
```

```
18155          H2(I)=Signals(20,1)
18160          H3(I)=Signals(21,1)
18165       ELSE
18170          H1(I)=Signals(19,Nscans)
18175          H2(I)=Signals(20,Nscans)
18180          H3(I)=Signals(21,Nscans)
18185       END IF
18190    ELSE
18195       H1(I)=Signals(19,Time_index)
18200       H2(I)=Signals(20,Time_index)
18205       H3(I)=Signals(21,Time_index)
18210    END IF
18215 NEXT I
18220 L=0
18225 FOR I=X_filter_min+1-4*Post_size TO Xmax+4*Post_size STEP 4
18230    L=L+1
18235    MAT F1= Pre_filter*H1
18240    MAT F2= Pre_filter*H2
18245    MAT F3= Pre_filter*H3
18250    Filter_temp(L,19)=F1(1)
18255    Filter_temp(L,20)=F2(1)
18260    Filter_temp(L,21)=F3(1)
18265    MAT REORDER H1 BY B
18270    MAT REORDER H2 BY B
18275    MAT REORDER H3 BY B
18280    FOR J=1 TO 4
18285       IF ((I+J+Pre_size)<=0) OR ((I+J+Pre_size)>Nscans) THEN
18290          IF (I+J+Pre_size)<=0 THEN
18295             H1(Total_size-4+J)=Signals(19,1)
18300             H2(Total_size-4+J)=Signals(20,1)
18305             H3(Total_size-4+J)=Signals(21,1)
18310          ELSE
18315             H1(Total_size-4+J)=Signals(19,Nscans)
18320             H2(Total_size-4+J)=Signals(20,Nscans)
18325             H3(Total_size-4+J)=Signals(21,Nscans)
18330          END IF
18335       ELSE
18340          H1(Total_size-4+J)=Signals(19,I+J+Pre_size)
18345          H2(Total_size-4+J)=Signals(20,I+J+Pre_size)
18350          H3(Total_size-4+J)=Signals(21,I+J+Pre_size)
18355       END IF
18360    NEXT J
18365 NEXT I
18370 DEALLOCATE B(*)
18375 DEALLOCATE H1(*)
18380 DEALLOCATE H2(*)
18385 DEALLOCATE H3(*)
18390   !
18395   !     POST FILTER
18400   !
18405 DISP "PERFORMING POST-FILTERING OF DATA"
18410 Total_size=Post_size*2+1
18415 ALLOCATE INTEGER B(1:Total_size)
18420 FOR I=1 TO Total_size-1
18425    B(I)=I+1
18430 NEXT I
18435 B(Total_size)=1
18440 ALLOCATE REAL H1(1:Total_size)
18445 ALLOCATE REAL H2(1:Total_size)
18450 ALLOCATE REAL H3(1:Total_size)
18455 FOR I=1 TO Total_size
18460    H1(I)=Filter_temp(I,19)
18465    H2(I)=Filter_temp(I,20)
18470    H3(I)=Filter_temp(I,21)
18475 NEXT I
18480 L=0
```

```
18485  FOR I=X_filter_min+1 TO Xmax STEP 4
18490     L=L+1
18495     MAT F1= Post_filter*H1
18500     MAT F2= Post_filter*H2
18505     MAT F3= Post_filter*H3
18510     Signals(24,I)=INT(F1(1)+.5)
18515     Signals(25,I)=INT(F2(1)+.5)
18520     Signals(26,I)=INT(F3(1)+.5)
18525     Temp_pos=(F1(1)/F3(1)*Scale_factor(27)+.5)
18530     IF ABS(Temp_pos)<32677 THEN Signals(27,I)=INT(Temp_pos)
18535     Temp_pos=-1*(F2(1)/F3(1)*Scale_factor(28)+.5)          ! TO TAKE INTO
18540                ! ACCOUNT SENSE OF SPINDLE TORQUE SIGNAL
18545     IF ABS(Temp_pos)<32677 THEN Signals(28,I)=INT(Temp_pos)
18550     MAT REORDER H1 BY B
18555     MAT REORDER H2 BY B
18560     MAT REORDER H3 BY B
18565     H1(Total_size)=Filter_temp(L+Total_size,19)
18570     H2(Total_size)=Filter_temp(L+Total_size,20)
18575     H3(Total_size)=Filter_temp(L+Total_size,21)
18580  NEXT I
18585  FOR I=X_filter_min+1 TO Xmax-4 STEP 4
18590     FOR J=1 TO 3
18595        FOR L=24 TO 28
18600           Temp_pos=((Signals(L,I+4)*1.0-Signals(L,I))*J*.25+Signals(L,I)+.
5)
18605           IF ABS(Temp_pos)<32677 THEN Signals(L,I+J)=INT(Temp_pos)
18610        NEXT L
18615     NEXT J
18620  NEXT I
18625  DISP "FILTERING DONE"
18630  DEALLOCATE B(*)
18635  DEALLOCATE Filter_temp(*)
18640  DEALLOCATE H1(*)
18645  DEALLOCATE H2(*)
18650  DEALLOCATE H3(*)
18655  GRAPHICS ON
18660  BEEP
18665  RETURN
18670 !
18675 ! ================================================================
18680 !   SIGNAL FILTER  -  DIGITALLY FILTER ANY CHANNEL
18685 ! ================================================================
18690 Signal_filter:   !
18695  IF NOT Filter_flag THEN GOSUB Filter_design
18700  GRAPHICS OFF
18705  Filter_channel=Channel_y
18710  ALLOCATE REAL Filter_temp_2(1:7000)
18715    !
18720    !   PRE FILTER
18725    !
18730  DISP "PERFORMING PRE-FILTERING OF DATA"
18735  Total_size=Pre_size*2+1
18740  ALLOCATE INTEGER B(1:Total_size)
18745  FOR I=1 TO Total_size-4
18750     B(I)=I+4
18755  NEXT I
18760  FOR I=1 TO 4
18765     B(I+Total_size-4)=I
18770  NEXT I
18775  ALLOCATE REAL H1(1:Total_size)
18780  X_filter_min=MAX(1,INT(1000*X_time_min/Corr_factor))
18785  X_filter_max=MIN(INT(5+1000*X_time_max/Corr_factor),Nscans)
18790  FOR I=1 TO Total_size
18795     Time_index=I+X_filter_min-Pre_size-4*(Post_size)
18800     IF (Time_index<=0) THEN
18805        H1(I)=Signals(Channel_y,1)
```

```
18810    ELSE
18815       IF (Time_index>Nscans) THEN
18820          H1(I)=Signals(Channel_y,Nscans)
18825       ELSE
18830          H1(I)=Signals(Channel_y,Time_index)
18835       END IF
18840    END IF
18845 NEXT I
18850 L=0
18855 FOR I=X_filter_min+1-4*Post_size TO X_filter_max+4*Post_size STEP 4
18860    L=L+1
18865    MAT F1= Pre_filter*H1
18870    Filter_temp_2(L)=F1(1)
18875    MAT REORDER H1 BY B
18880    FOR J=1 TO 4
18885       IF ((I+J)<=0) THEN
18890          H1(Total_size-4+J)=Signals(Channel_y,1)
18895       ELSE
18900          IF ((I+J+Pre_size)>Nscans) THEN
18905             H1(Total_size-4+J)=Signals(Channel_y,Nscans)
18910          ELSE
18915             H1(Total_size-4+J)=Signals(Channel_y,I+J+Pre_size)
18920          END IF
18925       END IF
18930    NEXT J
18935 NEXT I
18940 DEALLOCATE B(*)
18945 DEALLOCATE H1(*)
18950   !
18955   !     POST FILTER
18960   !
18965 DISP "PERFORMING POST-FILTERING OF DATA"
18970 Total_size=Post_size*2+1
18975 ALLOCATE INTEGER B(1:Total_size)
18980 FOR I=1 TO Total_size-1
18985    B(I)=I+1
18990 NEXT I
18995 B(Total_size)=1
19000 ALLOCATE REAL H1(1:Total_size)
19005 FOR I=1 TO Total_size
19010    H1(I)=Filter_temp_2(I)
19015 NEXT I
19020 L=0
19025 FOR I=X_filter_min+1 TO X_filter_max STEP 4
19030    L=L+1
19035    MAT F1= Post_filter*H1
19040    Signals(35,I)=INT(F1(1)+.5)
19045    MAT REORDER H1 BY B
19050    H1(Total_size)=Filter_temp_2(L+Total_size)
19055 NEXT I
19060 FOR I=X_filter_min+1 TO X_filter_max-4 STEP 4
19065    FOR J=1 TO 3
19070       Temp_pos=((Signals(35,I+4)*1.0-Signals(35,I))*J*.25+Signals(35,I)+.
5)
19075       IF ABS(Temp_pos)<32677 THEN Signals(35,I+J)=INT(Temp_pos)
19080    NEXT J
19085 NEXT I
19090 DISP "FILTERING DONE"
19095 DEALLOCATE B(*)
19100 DEALLOCATE Filter_temp_2(*)
19105 DEALLOCATE H1(*)
19110 DISP "TO VIEW FILTERED DATA PLOT CHANNEL # 35"
19115 BEEP
19120 GRAPHICS ON
19125 RETURN
19130 !
```

```
19135 ! ========================================================================
19140 ! FL DES
19145 ! ========================================================================
19150 Fl_des:!
19155  PRINT CHR$(12)
19160  PRINT "BEFORE ANY DATA CAN BE FILTERED , THE FILTER MUST BE DESIGNED."
19165  PRINT "THE FILTER ITSELF CONSISTS OF TWO PARTS: A PRE-FILTER ,AND; A"
19170  PRINT "POST-FILTER. THIS IS DONE TO SPEED UP THE FILTERING PROCESS."
19175  PRINT "ONCE THE FILTERS ARE DESIGNED , THEY MAY BE USED OVER AND OVER"
19180  PRINT "AGAIN UNTIL A NEW FILTER DESIGN IS DESIRED."
19185  PRINT "THE INSTRUCTIONS ASK FOR THE FOLLOWING ITEMS:"
19190  PRINT "Ripple, dB: "
19195  PRINT "Rejection, dB: "
19200  PRINT "Upper Limit of Pass Band, Hz: "
19205  PRINT "Lower Limit of Stop Band, Hz: "
19210  PRINT
19215  PRINT "THESE ARE INPUT FOR THE PRE-FILTER AND AGAIN FOR THE POST-FILTER."
19220  PRINT "THE LIMITS IMPOSED ON THE PRE-FILTER SHOULD NOT BE AS STRINGENT"
19225  PRINT "AS THE ONES ON THE POST-FILTER."
19230  PRINT "THE FILTER DESIGNED IS A 'LOW PASS' FILTER"
19235  PRINT "THE INPUT TERMS ARE DESCRIBED ON THE FOLLOWING PAGE."
19240  DISP "<<<<<<<<<<<<<<<<PRESS CONT FOR NEXT PAGE>>>>>>>>>>>>>>>"
19245  PAUSE
19250  DISP ""
19255  PRINT " ";CHR$(124);"            UPPER LIMIT OF PASS BAND Hz"
19260  PRINT "F";CHR$(124);"           /"
19265  PRINT "I";CHR$(124);"  *       *  -----------------------------"
19270  PRINT "L";CHR$(124);" * *     * *        ^"
19275  PRINT "T";CHR$(124);"    *   *   *       RIPPLE Db.     -------"
19280  PRINT "E";CHR$(124);"     * *     *      ^               ^"
19285  PRINT "R";CHR$(124);"      *  -----+--------             ^"
19290  PRINT " ";CHR$(124);"               *                    REJECTION Db."
19295  PRINT "G";CHR$(124);"                *                   ^"
19300  PRINT "A";CHR$(124);"                 *                  ^"
19305  PRINT "I";CHR$(124);"                  +-----+-----+-----------"
19310  PRINT "N";CHR$(124);"                   *   * *   * *"
19315  PRINT " ";CHR$(124);"                    * *   * *   * *"
19320  PRINT "D";CHR$(124);"                     *     *     *"
19325  PRINT "b";CHR$(124);"                     /"
19330  PRINT " ";CHR$(124);"                     LOWER LIMIT OF PASS BAND Hz"
19335  PRINT " ";CHR$(124);
19340  FOR I=1 TO 50
19345     PRINT CHR$(95);
19350  NEXT I
19355  PRINT CHR$(95)
19360  PRINT "                       FREQUENCY Hz"
19365  RETURN
19370 !
19375 ! ==============================================================
19380 !   FILTER DESIGN
19385 ! ==============================================================
19390 Filter_design:   !
19395  RAD
19400  GRAPHICS OFF
19405  W=1000
19410  Ripple=.1
19415  Rejection=40
19420  Upper_limit=125
19425  Lower_limit=175
19430  Post_filter_flg=0
19435  GOSUB Calc_filter
19440  Pre_size=Filter_size
19445  PRINT "NUMBER OF TERMS IN PRE-FILTER ";Filter_size*2+1
19450  DEALLOCATE Pre_filter(*)
19455  ALLOCATE REAL Pre_filter(-Pre_size:Pre_size)
19460  FOR I=-Pre_size TO Pre_size
```

```
19465      Pre_filter(I)=Filter(ABS(I))
19470  NEXT I
19475  DEALLOCATE Filter(*)
19480     !
19485  Ripple=.1
19490  Rejection=40
19495  Upper_limit=50
19500  Lower_limit=75
19505  Post_filter_flg=1
19510  GOSUB Calc_filter
19515  Post_size=Filter_size
19520  PRINT "NUMBER OF TERMS IN POST-FILTER  ";Filter_size*2+1
19525  DEALLOCATE Post_filter(*)
19530  ALLOCATE REAL Post_filter(-Post_size:Post_size)
19535  FOR I=-Post_size TO Post_size
19540     Post_filter(I)=Filter(ABS(I))
19545  NEXT I
19550  DEALLOCATE Filter(*)
19555     !
19560  Y$=" "
19565  INPUT "DO YOU LIKE THIS FILTER DESIGN? Y or N",Y$
19570  IF UPC$(Y$)="N" THEN Filter_design
19575  Filter_flag=1
19580  PRINT CHR$(12)
19585  DEG
19590  GRAPHICS ON
19595  RETURN
19600 !
19605 ! ============================================================
19610 !   CALCULATE FILTER
19615 ! ============================================================
19620 Calc_filter:    !
19625  W=Scan_rate
19630  IF NOT Post_filter_flg THEN
19635     PRINT "-------------PRE-FILTER DESIGN -------------- "
19640     PRINT
19645  ELSE
19650     PRINT
19655     W=.25*W
19660     PRINT "-------------POST-FILTER DESIGN ------------- "
19665     PRINT
19670  END IF
19675  BEEP
19680  Ripple_temp=Ripple
19685  PRINT "CURRENT Ripple --------------- = ";Ripple;" dB: RE-ENTER or CONT"
19690  INPUT Ripple
19695  IF Ripple_temp<>Ripple THEN PRINT "  NEW Ripple ---------------- = ";Ripp
le;" dB"
19700  BEEP
19705  Rejection_temp=Rejection
19710  PRINT "CURRENT Rejection ----------- = ";Rejection;" dB: RE-ENTER or CONT
"
19715  INPUT Rejection
19720  IF Rejection_temp<>Rejection THEN PRINT "  NEW Rejection ------------- =
";Rejection;" dB"
19725  BEEP
19730  Upper_limit_tem=Upper_limit
19735  PRINT "CURRENT Pass Band Upper Limit = ";Upper_limit;" Hz: RE-ENTER or CO
NT"
19740  INPUT Upper_limit
19745  IF Upper_limit_tem<>Upper_limit THEN PRINT "  NEW Pass Band Upper Limit
 = ";Upper_limit;" Hz"
19750  BEEP
19755  Lower_limit_tem=Lower_limit
19760  PRINT "CURRENT Stop Band Lower Limit = ";Lower_limit;" Hz: RE-ENTER or CO
NT"
```

```
19765  INPUT Lower_limit
19770  IF Lower_limit_tem<>Lower_limit THEN PRINT "   NEW Stop Band Lower Limit
 = ";Lower_limit;" Hz"
19775  Because=ABS(Lower_limit-Upper_limit)
19780  Lower_limit=Upper_limit+Because/2
19785  Ripple=10^(.05*Ripple)
19790  Rejection=10^(-.05*Rejection)
19795  Ratio=MIN(Rejection,(Ripple-1)/(Ripple+1))
19800  Ratio=-20*LGT(Ratio)
19805  E=0
19810  IF Ratio>50 THEN E=.1102*(Ratio-8.7)
19815  IF Ratio>21 AND Ratio<=50 THEN E=.5842*(Ratio-21)^.4+.07886*(Ratio-21)
19820  IF E=0 THEN
19825     Ix(2)=1
19830  ELSE
19835     Ix(2)=FNI(E)
19840  END IF
19845  D=.9222
19850  IF Ratio>21 THEN D=(Ratio-7.95)/14.36
19855  Filter_size=INT(D*W/Because+1)
19860  IF Filter_size MOD 2=0 THEN Filter_size=Filter_size+1
19865  Filter_size=(Filter_size-1)/2
19870  ALLOCATE REAL Filter(0:Filter_size)
19875  Filter(0)=Lower_limit*2/W
19880  Total_filter=Filter(0)
19885  FOR I=1 TO Filter_size
19890     Filter(I)=SIN(Lower_limit*I*2*PI/W)/(PI*I)
19895     X=E*SQR(1-(I/Filter_size)^2)
19900     IF X=0 THEN
19905        Ix(1)=1
19910     ELSE
19915        Ix(1)=FNI(X)
19920     END IF
19925     Filter(I)=Filter(I)*Ix(1)/Ix(2)
19930     Total_filter=Total_filter+2*Filter(I)
19935  NEXT I
19940  FOR I=0 TO Filter_size
19945     Filter(I)=Filter(I)/Total_filter
19950  NEXT I
19955  RETURN
19960  !
19965  ! ======================================================================
19970  ! STAT
19975  ! ======================================================================
19980 Stat:!
19985  PRINT CHR$(12)
19990  PRINT "THIS ROUTINE IS USED TO DETERMINE :"
19995  PRINT "   BLADE ORIENTATION AT START OF INTERACTION - deg;"
20000  PRINT "   BLADE ORIENTATION AT THE PEAK OF THE INTERACTION - deg;"
20005  PRINT "   BLADE IMPACT DURATION - deg;"
20010  PRINT "   EVENT DURATION TIME - sec, AND;"
20015  PRINT "   INTERACTION ENERGY - kJ."
20020  PRINT
20025  PRINT "THE PROGRAM HAS BEEN FURTHER MODIFIED TO DETERMINE THE LOAD"
20030  PRINT "LOCATION ."
20035  PRINT "IN EACH OF THESE CASES THE DATA IS STORED ON AN INTERMEDIATE"
20040  PRINT "STATISTICS DISK. THE DATA IS TRANSFERRED FROM THE INTERMEDIATE"
20045  PRINT "DISK TO THE STATSDISK USING EITHER THE PROGRAM 'BLADESTATS' or"
20050  PRINT "'BLADESTAT1'."
20055  RETURN
20060  !
20065  ! ======================================================================
20070  ! STAT ORIENT
20075  ! ======================================================================
20080 Stat_orient:!
20085  PRINT "NO HELP IN STAT ORIENT ROUTINE"
```

```
20090  RETURN
20095 !
20100 !
20105 ! ====================================================================
20110 ! STAT TORQUE
20115 ! ====================================================================
20120 Stat_torque:!
20125  PRINT "NO HELP IN STAT TORQUE ROUTINE"
20130  RETURN
20135 !
20140 ! ============================================================
20145 ! STATISTICS ROUTINES
20150 ! ============================================================
20155 Statistics:!
20160  IF Test_number=0 THEN
20165      INPUT "INPUT DYNAMIC TEST # : Test_number",Test_number
20170  END IF
20175  Number_of_times=0
20180  MAT Times= (0)
20185  Torque_flag=0
20190  Rad_flag=0
20195  Circ_flag=0
20200  Minmaxmean_flag=0
20205  Orient_flag=0
20210  GOSUB Stats_keys
20215  Exit_stats=0
20220  !
20225 Wait_loop_stats:   !
20230  IF NOT Exit_stats THEN Wait_loop_stats
20235  DISP ""
20240  GOTO Main_loop
20245 !
20250 ! ============================================================
20255 !   STATISTICS KEYS
20260 ! ============================================================
20265 Stats_keys:   !
20270  OFF KEY
20275  ON KEY 0 LABEL "READ/PRT EVENT " GOSUB Read_event
20280  ON KEY 10 GOSUB Print_event
20285  ON KEY 1 LABEL "STORE EVENT" GOSUB Store_event
20290  ON KEY 11 GOSUB Idle
20295  ON KEY 2 LABEL "ORIENT/HELP" GOSUB Calc_orient
20300  ON KEY 12 GOSUB Stat_orient
20305  ON KEY 3 LABEL "TORQ AREA/HELP" GOSUB Torque_area
20310  ON KEY 13 GOSUB Stat_torque
20315  ON KEY 4 LABEL "DUR./NEW DISK" GOSUB Event_duration
20320  ON KEY 14 GOTO New_disk
20325  ON KEY 5 LABEL "READ/PRT LOC" GOSUB Read_location
20330  ON KEY 15 GOSUB Print_location
20335  ON KEY 6 LABEL "STORE LOCATION" GOSUB Store_location
20340  ON KEY 16 GOSUB Idle
20345  ON KEY 7 LABEL "RAD/CIRC LOC." GOSUB Calc_radius
20350  ON KEY 17 GOSUB Calc_circ
20355  ON KEY 8 LABEL "MinMaxMean/EXIT" GOSUB Calc_minmaxmean
20360  ON KEY 18 GOSUB Exit_stats
20365  ON KEY 9 LABEL "SEL/DEL POINTS" GOSUB Select_point
20370  ON KEY 19 GOSUB Select_exit
20375  RETURN
20380 !
20385 ! ============================================================
20390 ! READING EVENT DATA
20395 ! ============================================================
20400 Read_event:!
20405  DISP "INSERT THE EVENT DATA DISC INTO THE RIGHT HAND DISC DRIVE THEN PUSH
 CONT"
20410  PAUSE
```

```
20415  DISP "READING EVENT DATA"
20420  ASSIGN @Event_data TO "EVENT_D"
20425  ENTER @Event_data;Dur_event(*),Blade_orien_p(*),Blade_orien_s(*),Blade_or
ien_e(*),Energy_torque(*)
20430  ASSIGN @Event_data TO *
20435  DISP ""
20440  RETURN
20445 !
20450 ! ====================================================================
20455 ! PRINT EVENT ROUTINE
20460 ! ====================================================================
20465 Print_event:    !
20470  INPUT "ENTER: First_event,Last_event",First_event,Last_event
20475  GOSUB Hardcopy
20480  IF Hard_copy THEN
20485     Lines=50
20490  ELSE
20495     Lines=10
20500  END IF
20505  Pages=INT((Last_event-First_event)/Lines+1)
20510  Start_event=First_event
20515  FOR I=1 TO Pages
20520     PRINT
20525     PRINT USING "5A,5X,8A,8X,17A,7X,6A";"EVENT","DURATION","BLADE ORIENTAT
ION","TORQUE"
20530     PRINT USING "2X,A,7X,8A,2X,8A,2X,7A,3X,6A,4X,6A";"#","OF EVENT","AT ST
ART","AT PEAK","AT END","ENERGY"
20535     PRINT
20540     PRINT USING "10X,6A,4X,6A,4X,6A,4X,6A,4X,4A";"(SEC.)","(DEG.)","(DEG.)
","(DEG.)","(KJ)"
20545     PRINT "______________________________________________________________"
20550     PRINT
20555     Stop_event=MIN((Start_event+Lines-1),Last_event)
20560     FOR J=Start_event TO Stop_event
20565        PRINT USING "MDDD,6X,5(MD.DDE,X)";J,Dur_event(J),Blade_orien_s(J),B
lade_orien_p(J),Blade_orien_e(J),Energy_torque(J)
20570     NEXT J
20575     IF NOT Hard_copy THEN
20580        DISP "PRESS ";I$;"CONT";N$;" FOR NEXT PAGE"
20585        PAUSE
20590     END IF
20595     Start_event=Start_event+Lines
20600     IF Start_event<=Last_event THEN PRINT CHR$(12)
20605  NEXT I
20610     !
20615  Hard_copy=0
20620  PRINTER IS 1
20625  DISP ""
20630  PRINT CHR$(12)
20635  RETURN
20640  !
20645 ! ====================================================================
20650 ! STORE EVENT ROUTINE
20655 ! ====================================================================
20660 Store_event:    !
20665  ON ERROR GOSUB Event_file
20670  DISP "STORING EVENT FILE TO DISK"
20675  ASSIGN @Event_data TO "EVENT_D"
20680  OUTPUT @Event_data;Dur_event(*),Blade_orien_p(*),Blade_orien_s(*),Blade_o
rien_e(*),Energy_torque(*)
20685  ASSIGN @Event_data TO *
20690  OFF ERROR
20695  DISP ""
20700  RETURN
20705     !
20710 ! ============================================================
20715 ! EVENT_FILE CREATES FILE FOR EVENT DATA
20720 ! ===============================================================
20725 Event_file:!
20730  IF ERRN=56 THEN
20735     CREATE BDAT "EVENT_D",INT((350*5*8+10)/256)+1
20740  ELSE
20745     DISP "UNEXPECTED ";ERRM$;" HAS OCCURED"
20750     PAUSE
20755  END IF
20760  RETURN
20765 !
20770 ! ===============================================================
20775 !    TORQUE AREA
20780 ! ===============================================================
20785 Torque_area:   !
20790  IF Number_of_times<2 THEN RETURN
20795  IF Channel_y<>9 THEN
20800     DISP "NOT THE TORQUE CHANNEL YOU SILLY BURGER"
20805     BEEP
20810     WAIT 1
20815     GOSUB Exit_stats
20820     RETURN
20825  END IF
20830  GOSUB Calc_torque
20835  RETURN
20840 !
20845 ! ===============================================================
20850 !    SELECT_EXIT
20855 ! ===============================================================
20860 Select_exit:   !
20865  IF Number_of_times>0 THEN
20870     PEN 0
20875     FOR I=1 TO Number_of_times
20880        MOVE Times(I)*Corr_factor,Signals(Channel_y,Times(I))/Scale_factor(
Channel_y)*Slope(Channel_y)+Offset(Channel_y)-.05*Y_scale
20885        IF I=1 THEN LABEL CHR$(91)
20890        IF I=2 THEN LABEL CHR$(94)
20895        IF I=3 THEN LABEL CHR$(93)
20900     NEXT I
20905  END IF
20910  PEN 1
20915  Number_of_times=0
20920  MAT Times= (0)
20925  Torque_flag=0
20930  Rad_flag=0
20935  Circ_flag=0
20940  Minmaxmean_flag=0
20945  Orient_flag=0
20950  DISP ""
20955  RETURN
20960 !
20965 ! ===============================================================
20970 !    SELECT POINT
20975 ! ===============================================================
20980 Select_point:   !
20985  IF Number_of_times>=3 THEN Number_of_times=0
20990  Number_of_times=Number_of_times+1
20995  Times(Number_of_times)=Current_record
21000  PEN 0
21005  MOVE Current_record*Corr_factor,Signals(Channel_y,Current_record)/Scale_f
actor(Channel_y)*Slope(Channel_y)+Offset(Channel_y)-.05*Y_scale
21010  IF Number_of_times=1 THEN LABEL CHR$(91)
21015  IF Number_of_times=2 THEN LABEL CHR$(94)
21020  IF Number_of_times=3 THEN LABEL CHR$(93)
21025  IF Number_of_times=2 THEN
21030     Start_point=MIN(Times(1),Times(2))
```

```
21035     Finish_point=MAX(Times(1),Times(2))
21040  END IF
21045  IF Number_of_times=3 THEN
21050     Start_point=MIN(Times(1),Times(2),Times(3))
21055     Finish_point=MAX(Times(1),Times(2),Times(3))
21060  END IF
21065  PEN 1
21070  RETURN
21075 !
21080 ! ===============================================================
21085 !    CALCULATE ORIENTATION ANGLE OF PROPELLER
21090 ! ===============================================================
21095 Calc_orient:   !
21100  IF Number_of_times<3 THEN RETURN
21105  DISP "HOLD ON ...."
21110  MAT SORT Times
21115  This_point=Times(1)
21120  GOSUB Find_prop_angle
21125  Prop_angle(1)=(Found_angle+60) MOD 360
21130  This_point=Times(2)
21135  GOSUB Find_prop_angle
21140  Prop_angle(2)=(Found_angle+60) MOD 360
21145  This_point=Times(3)
21150  GOSUB Find_prop_angle
21155  Prop_angle(3)=(Found_angle+60) MOD 360
21160     !
21165  Blade_orien_s(Test_number)=Prop_angle(1)     ! BLADE ORIENTATION START
21170  Blade_orien_p(Test_number)=Prop_angle(2)     ! BLADE ORIENTATION PEAK
21175  Blade_orien_e(Test_number)=Prop_angle(3)     ! BLADE ORIENTATION END
21180  GOSUB Hardcopy
21185  IF Hard_copy THEN
21190     PRINT USING "7A,DDD,3(10A,DDD.DDD)";"TEST # ",Test_number," ANGLE 1: "
,Prop_angle(1)," ANGLE 2: ",Prop_angle(2)," ANGLE 3: ",Prop_angle(3)
21195     Hard_copy=0
21200     PRINTER IS 1
21205  ELSE
21210     DISP I$;"TEST # ";Test_number;" 1: ";Prop_angle(1);" 2: ";Prop_angle(2
);" 3: ";Prop_angle(3);N$
21215  END IF
21220  RETURN
21225 !
21230 ! ===============================================================
21235 !    FIND PROPELLER ANGLES
21240 ! ===============================================================
21245 Find_prop_angle:   !
21250  DISP "HOLD ON ...."
21255  FOR I=1 TO Numb_of_pulse
21260     IF Rpm_pulse(I)>This_point THEN Start_pulse
21265  NEXT I
21270 Start_pulse:      !
21275  Found_angle=(This_point-Rpm_pulse(I-1))/(Rpm_pulse(I)-Rpm_pulse(I-1))*360
21280  RETURN
21285 !
21290 ! ===============================================================
21295 !    CALCULATE TORQUE AREA
21300 ! ===============================================================
21305 Calc_torque:   !
21310  DISP "HOLD ON ...."
21315  Start_height=Signals(9,Start_point)
21320  Finish_height=Signals(9,Finish_point)
21325  Hydro_area=(.5*(Start_height+Finish_height)/Scale_factor(9)*Slope(9)+Offs
et(9))*(Finish_point-Start_point)
21330  Total_height=(Start_height+Finish_height)/2
21335  FOR I=Start_point+1 TO Finish_point-1
21340     Total_height=Total_height+Signals(9,I)
21345  NEXT I
```

```
21350  Total_area=(Total_height/Scale_factor(9)*Slope(9)+Offset(9))
21355  Inter_area=Total_area-Hydro_area
21360  Av_inter_tq=Inter_area/(Finish_point-Start_point)
21365  !
21370    !"CALCULATE MEAN SHAFT SPEED"
21375  Freq_sum=(Signals(34,Start_point)+Signals(34,Finish_point))/2
21380  FOR I=Start_point+1 TO Finish_point-1
21385     Freq_sum=Freq_sum+Signals(34,I)
21390  NEXT I
21395  IF Freq_sum<>0 THEN
21400     Freq_mean=((Freq_sum/Scale_factor(34)*Slope(34)+Offset(34))/(Finish_po
int-Start_point))/60 !FREQ. IN HZ
21405     Rad_rotation=2*PI*Freq_mean*(Finish_point-Start_point)/Scan_rate
21410  ELSE
21415     PRINT "THERE IS NO SHAFT SPEED SIGNAL DURING THIS TIME PERIOD"
21420     RETURN
21425  END IF
21430    !
21435  Torque_energy=Av_inter_tq*Rad_rotation      ! ENERGY IN KJ
21440  Torque_power=Torque_energy/((Finish_point-Start_point)/Scan_rate) !POWER
kW
21445  Energy_torque(Test_number)=Torque_energy
21450  GOSUB Hardcopy
21455  Spsr=INT((Start_point/Scan_rate)*1000+.5)/1000
21460  Fpsr=INT((Finish_point/Scan_rate)*1000+.5)/1000
21465  Torque_energy=INT((Torque_energy)*10+.5)/10
21470  Torque_power=INT((Torque_power)*10+.5)/10
21475  IF Hard_copy THEN
21480     PRINT "TEST #";Test_number;" FROM ";Spsr;" TO ";Fpsr;" sec. INT ENERGY
 =";Torque_energy;" kJ";"POWER =";Torque_power;" kW"
21485     Hard_copy=0
21490     PRINTER IS 1
21495  ELSE
21500     DISP I$;"FROM ";Spsr;" TO ";Fpsr;" sec. ENERGY=";Torque_energy;" kJ";"
 INT POWER=";Torque_power;" kW";N$
21505  END IF
21510  RETURN
21515 !
21520 ! ============================================================
21525 !   FIND MIN, MAX AND MEAN OF DATA BETWEEN SPECIFIED TIMES
21530 ! ============================================================
21535 Find_min_max:   !
21540  Points_span=Finish_point-Start_point+1
21545  !
21550  IF One_channel THEN
21555     Max_value(Channel_y)=-32767
21560     Min_value(Channel_y)=32767
21565     Mean_value(Channel_y)=0
21570     FOR J=Start_point TO Finish_point
21575        Min_value(Channel_y)=MIN(Min_value(Channel_y),Signals(Channel_y,J))
21580        Max_value(Channel_y)=MAX(Max_value(Channel_y),Signals(Channel_y,J))
21585        Mean_value(Channel_y)=Mean_value(Channel_y)+Signals(Channel_y,J)
21590     NEXT J
21595     Mean_value(Channel_y)=(Mean_value(Channel_y)/Scale_factor(Channel_y))/
Points_span*Slope(Channel_y)+Offset(Channel_y)
21600     Min_value(Channel_y)=(Min_value(Channel_y)/Scale_factor(Channel_y))*Sl
ope(Channel_y)+Offset(Channel_y)
21605     Max_value(Channel_y)=(Max_value(Channel_y)/Scale_factor(Channel_y))*Sl
ope(Channel_y)+Offset(Channel_y)
21610     IF Min_value(Channel_y)>Max_value(Channel_y) THEN
21615        Temp_val=Max_value(Channel_y)
21620        Max_value(Channel_y)=Min_value(Channel_y)
21625        Min_value(Channel_y)=Temp_val
21630     END IF
21635     IF NOT Time_plot THEN
21640        Max_value(Channel_x)=-32767
```

```
21645        Min_value(Channel_x)=32767
21650        Mean_value(Channel_x)=0
21655        FOR J=Start_point TO Finish_point
21660           Min_value(Channel_x)=MIN(Min_value(Channel_x),Signals(Channel_x,
J))
21665           Max_value(Channel_x)=MAX(Max_value(Channel_x),Signals(Channel_x,
J))
21670           Mean_value(Channel_x)=Mean_value(Channel_x)+Signals(Channel_x,J)
21675        NEXT J
21680        Mean_value(Channel_x)=(Mean_value(Channel_x)/Scale_factor(Channel_x
))/Points_span*Slope(Channel_x)+Offset(Channel_x)
21685        Min_value(Channel_x)=(Min_value(Channel_x)/Scale_factor(Channel_x))
*Slope(Channel_x)+Offset(Channel_x)
21690        Max_value(Channel_x)=(Max_value(Channel_x)/Scale_factor(Channel_x))
*Slope(Channel_x)+Offset(Channel_x)
21695        IF Min_value(Channel_x)>Max_value(Channel_x) THEN
21700           Temp_val=Max_value(Channel_x)
21705           Max_value(Channel_x)=Min_value(Channel_x)
21710           Min_value(Channel_x)=Temp_val
21715        END IF
21720     END IF
21725  ELSE
21730     FOR I=1 TO 18
21735        IF I=11 OR I=14 OR I=15 THEN Next_min_max
21740        DISP "FINDING MIN MAX MEAN FOR CHANNEL #";I
21745        Min_value(I)=2500
21750        Max_value(I)=-2500
21755        Mean_value(I)=0
21760        FOR J=Start_point TO Finish_point
21765           Min_value(I)=MIN(Min_value(I),Signals(I,J))
21770           Max_value(I)=MAX(Max_value(I),Signals(I,J))
21775           Mean_value(I)=Mean_value(I)+Signals(I,J)
21780        NEXT J
21785        Mean_value(I)=(Mean_value(I)/Scale_factor(I))/Points_span*Slope(I)+
Offset(I)
21790        Min_value(I)=(Min_value(I)/Scale_factor(I))*Slope(I)+Offset(I)
21795        Max_value(I)=(Max_value(I)/Scale_factor(I))*Slope(I)+Offset(I)
21800        IF Min_value(I)>Max_value(I) THEN
21805           Temp_val=Max_value(I)
21810           Max_value(I)=Min_value(I)
21815           Min_value(I)=Temp_val
21820        END IF
21825 Next_min_max:         !
21830     NEXT I
21835     IF Calculate_flag THEN
21840        FOR I=19 TO 21
21845           DISP "FINDING MIN MAX MEAN FOR CHANNEL #";I
21850           Min_value(I)=32767
21855           Max_value(I)=-32767
21860           Mean_value(I)=0
21865           FOR J=Start_point TO Finish_point
21870              Min_value(I)=MIN(Min_value(I),Signals(I,J))
21875              Max_value(I)=MAX(Max_value(I),Signals(I,J))
21880              Mean_value(I)=Mean_value(I)+Signals(I,J)
21885           NEXT J
21890           Mean_value(I)=(Mean_value(I)/Scale_factor(I))/Points_span*Slope(
I)+Offset(I)
21895           Min_value(I)=(Min_value(I)/Scale_factor(I))*Slope(I)+Offset(I)
21900           Max_value(I)=(Max_value(I)/Scale_factor(I))*Slope(I)+Offset(I)
21905           IF Min_value(I)>Max_value(I) THEN
21910              Temp_val=Max_value(I)
21915              Max_value(I)=Min_value(I)
21920              Min_value(I)=Temp_val
21925           END IF
21930        NEXT I
21935     END IF
```

```
21940     IF NOT Any_rpm_pulse OR Numb_of_pulse<3 THEN
21945        Min_value(34)=-1.E+6
21950        Max_value(34)=-1.E+6
21955        Mean_value(34)=-1.E+6
21960     ELSE
21965        DISP "FINDING MIN MAX MEAN FOR SHAFT RPM"
21970        Min_value(34)=32767
21975        Max_value(34)=0
21980        Mean_value(34)=0
21985        FOR I=2 TO Numb_of_pulse-1
21990           Min_value(34)=MIN(Min_value(34),Rpm(I))
21995           Max_value(34)=MAX(Max_value(34),Rpm(I))
22000           Mean_value(34)=Mean_value(34)+Rpm(I)
22005        NEXT I
22010        Mean_value(34)=(Mean_value(34)/Scale_factor(34))/(Numb_of_pulse-2)*
Slope(34)+Offset(34)
22015        Min_value(34)=(Min_value(34)/Scale_factor(34))*Slope(34)+Offset(34)
22020        Max_value(34)=(Max_value(34)/Scale_factor(34))*Slope(34)+Offset(34)
22025        IF Min_value(34)>Max_value(34) THEN
22030           Temp_val=Max_value(34)
22035           Max_value(34)=Min_value(34)
22040           Min_value(34)=Temp_val
22045        END IF
22050     END IF
22055  END IF
22060  RETURN
22065 !
22070 ! ==================================================================
22075 ! EVENT DURATION ROUTINE
22080 ! ==================================================================
22085 Event_duration:    !
22090  INPUT "ENTER THE DURATION OF THE EVENT",Dur_event(Test_number)
22095  RETURN
22100 !
22105 ! ==========================================================
22110 ! READING LOCATION DATA
22115 ! ==========================================================
22120 Read_location:!
22125  DISP "INSERT LOCATION DATA DISC INTO THE RIGHT DISC DRIVE AND PUSH CONT"
22130  PAUSE
22135  DISP "READING LOCATION DATA"
22140  ASSIGN @Location_data TO "LOC_D"
22145  ENTER @Location_data;Av_rad_loc(*),Av_circ_loc(*)
22150  ASSIGN @Location_data TO *
22155  DISP ""
22160  RETURN
22165 !
22170 ! ==================================================================
22175 ! PRINT LOCATION ROUTINE
22180 ! ==================================================================
22185 Print_location:    !
22190  INPUT "ENTER: First_event,Last_event",First_event,Last_event
22195  GOSUB Hardcopy
22200  IF Hard_copy THEN
22205     Lines=50
22210  ELSE
22215     Lines=10
22220  END IF
22225  Pages=INT((Last_event-First_event)/Lines+1)
22230  Start_event=First_event
22235  FOR I=1 TO Pages
22240     PRINT
22245     PRINT USING "5X,7A,3X,15A,3X,14A";"EVENT #","RADIAL LOCATION","CIRC. L
OCATION"
22250     PRINT
22255     PRINT USING "25X,A,14X,A";"m","m"
```

```
22260     PRINT "____________________________________________________________"
22265     PRINT
22270     PRINT
22275     Stop_event=MIN((Start_event+Lines-1),Last_event)
22280     FOR J=Start_event TO Stop_event
22285        PRINT USING "5X,DDD,12X,MD.DDE,12X,MD.DDE";J,Av_rad_loc(J),Av_circ_
loc(J)
22290     NEXT J
22295     IF NOT Hard_copy THEN
22300        DISP "PRESS ";I$;"CONT";N$;" FOR NEXT PAGE"
22305        PAUSE
22310     END IF
22315     Start_event=Start_event+Lines
22320     IF Start_event<=Last_event THEN PRINT CHR$(12)
22325  NEXT I
22330    !
22335  Hard_copy=0
22340  PRINTER IS 1
22345  DISP ""
22350  PRINT CHR$(12)
22355  RETURN
22360  !
22365 ! ======================================================================
22370 ! STORE LOCATION ROUTINE
22375 ! ======================================================================
22380 Store_location:    !
22385  DISP "STORING LOCATION DATA TO DISK"
22390  ON ERROR GOSUB Loc_d_file
22395  ASSIGN @Location_data TO "LOC_D"
22400  OUTPUT @Location_data;Av_rad_loc(*),Av_circ_loc(*)
22405  OFF ERROR
22410  ASSIGN @Location_data TO *
22415  DISP ""
22420  RETURN
22425 !
22430 ! ============================================================
22435 ! LOC_D_FILE CREATES FILE FOR LOCATION DATA
22440 ! ============================================================
22445 Loc_d_file:!
22450  IF ERRN=56 THEN
22455     CREATE BDAT "LOC_D",INT((350*2*8+10+2*3*350*8+20)/256)+1
22460  ELSE
22465     DISP "UNEXPECTED ";ERRM$;" HAS OCCURED"
22470     PAUSE
22475  END IF
22480  RETURN
22485 !
22490 ! ============================================================
22495 ! CALC_RADIUS
22500 ! ============================================================
22505 Calc_radius:!
22510  IF Number_of_times<2 THEN RETURN
22515  DISP "HOLD ON ...."
22520  One_channel=1
22525  Hold_channel=Channel_y
22530  Channel_y=22
22535  GOSUB Find_min_max
22540  One_channel=0
22545  A_ok$=""
22550  DISP "AV RAD LOC = ";Mean_value(Channel_y);" m. IS THIS OK : ";I$;"Y";N$;
" or ";I$;"CONT";N$;
22555  INPUT A_ok$
22560  DISP ""
22565  IF UPC$(A_ok$[1,1])="Y" THEN Av_rad_loc(Test_number)=Mean_value(Channel_y
)
22570  Channel_y=Hold_channel
```

```
22575  RETURN
22580            !
22585 ! ==============================================================
22590 ! CALC_CIRC
22595 ! ==============================================================
22600 Calc_circ:!
22605  IF Number_of_times<2 THEN RETURN
22610  DISP "HOLD ON ...."
22615  One_channel=1
22620  Hold_channel=Channel_y
22625  Channel_y=23
22630  GOSUB Find_min_max
22635  One_channel=0
22640  A_ok$=""
22645  DISP "AV CIRC LOC = ";Mean_value(Channel_y);" m. IS THIS OK : ";I$;"Y";N$
;" or ";I$;"CONT";N$;
22650  INPUT A_ok$
22655  IF UPC$(A_ok$[1,1])="Y" THEN Av_circ_loc(Test_number)=Mean_value(Channel_
y)
22660  DISP ""
22665  Channel_y=Hold_channel
22670  RETURN
22675 !
22680 ! ==============================================================
22685 ! CALC_MINMAXMEAN
22690 ! ==============================================================
22695 Calc_minmaxmean:!
22700  IF Number_of_times<2 THEN RETURN
22705  DISP "HOLD ON ...."
22710  One_channel=1
22715  GOSUB Find_min_max
22720  One_channel=0
22725  !
22730  GOSUB Hardcopy
22735  IF NOT Hard_copy THEN PRINT RPT$(CHR$(10),16)
22740  IF Time_plot THEN
22745     PRINT "Y-CHANNEL MINIMUM   MAXIMUM   MEAN"
22750  ELSE
22755     PRINT "X-CHANNEL MINIMUN   MAXIMUM   MEAN      Y-CHANNEL MINIMUM   MAX
IMUM   MEAN"
22760     PRINT USING "6D,#";Channel_x
22765     PRINT "     ";
22770     IF ABS(Min_value(Channel_x))<.01 OR ABS(Min_value(Channel_x))>=1000 TH
EN
22775        PRINT USING "MD.DDE,#";Min_value(Channel_x)
22780        PRINT " ";
22785     ELSE
22790        PRINT USING "MDDD.DDD,#";Min_value(Channel_x)
22795        PRINT "  ";
22800     END IF
22805     IF ABS(Max_value(Channel_x))<.01 OR ABS(Max_value(Channel_x))>=1000 TH
EN
22810        PRINT USING "MD.DDE,#";Max_value(Channel_x)
22815        PRINT " ";
22820     ELSE
22825        PRINT USING "MDDD.DDD,#";Max_value(Channel_x)
22830        PRINT "  ";
22835     END IF
22840     RETURN
22845     IF ABS(Mean_value(Channel_x))<.01 OR ABS(Mean_value(Channel_x))>=1000
THEN
22850        PRINT USING "MD.DDE,#";Mean_value(Channel_x)
22855        PRINT " ";
22860     ELSE
22865        PRINT USING "MDDD.DDD,#";Mean_value(Channel_x)
22870        PRINT "  ";
```

```
22875     END IF
22880  END IF
22885  !
22890  PRINT USING "6D,#";Channel_y
22895  PRINT "     ";
22900  IF ABS(Min_value(Channel_y))<.01 OR ABS(Min_value(Channel_y)))=1000 THEN
22905     PRINT USING "MD.DDE,#";Min_value(Channel_y)
22910     PRINT " ";
22915  ELSE
22920     PRINT USING "MDDD.DDD,#";Min_value(Channel_y)
22925     PRINT "  ";
22930  END IF
22935  IF ABS(Max_value(Channel_y))<.01 OR ABS(Max_value(Channel_y)))=1000 THEN
22940     PRINT USING "MD.DDE,#";Max_value(Channel_y)
22945     PRINT " ";
22950  ELSE
22955     PRINT USING "MDDD.DDD,#";Max_value(Channel_y)
22960     PRINT "  ";
22965  END IF
22970  IF ABS(Mean_value(Channel_y))<.01 OR ABS(Mean_value(Channel_y)))=1000 THE
N
22975     PRINT USING "MD.DDE,#";Mean_value(Channel_y)
22980  ELSE
22985     PRINT USING "MDDD.DDD,#";Mean_value(Channel_y)
22990  END IF
22995  PRINT
23000  IF NOT Hard_copy THEN
23005     DISP "PRESS ";I$;"CONT";N$
23010     PAUSE
23015     PRINT CHR$(12)
23020     DISP ""
23025  END IF
23030  Hard_copy=0
23035  PRINTER IS 1
23040  RETURN
23045 !
23050 ! ***********************************************************************
23055 ! HARDCOPY DETERMINES IF A PRINTOUT ON PAPER IS REQUIRED ****************
23060 ! ***********************************************************************
23065 Hardcopy: ! **************************************************************
23070  PRINTER IS 1
23075  Hard_copy=0
23080  Inpt$=""
23085  DISP "DO YOU WANT A HARD COPY , INPUT : ";I$;"Y";N$;" or ";I$;"CONT";N$;
23090  INPUT Inpt$
23095  IF UPC$(Inpt$[1,1])="Y" THEN
23100     PRINTER IS 701
23105     Hard_copy=1
23110  END IF
23115  RETURN
23120 !
23125 ! ==============================================================
23130 !    EXIT STATISTICS ROUTINE =====================================
23135 ! ==============================================================
23140 Exit_stats:    ! ================================================
23145  GOSUB Select_exit
23150  Exit_stats=1
23155  RETURN
23160  !
23165 ! ==============================================================
23170 !    SAVE TO DISC ================================================
23175 ! ==============================================================
23180 Save_to_disc:    ! ==============================================
23185  File$="STATS"&VAL$(Disc_number)
23190  ON ERROR GOSUB Duplicate_file
23195  CREATE BDAT File$&":INTERNAL,4,1",5
```

```
23200  ASSIGN @Data_file TO File$&":INTERNAL,4,1"
23205  OUTPUT @Data_file;Title$,Dates$,Times$,N_channels,Nscans,Scan_rate,Int_da
ta,Int_pointer,Min_value(*),Max_value(*),Mean_value(*)
23210  ASSIGN @Data_file TO *
23215  OFF ERROR
23220  RETURN
23225 Duplicate_file: !
23230  IF ERRN=54 THEN
23235     PRINT "DUPLICATE FILE FOR TEST # ";Test_number;" 'NEW' FILE CREATED"
23240     File$="NEW"&VAL$(Disc_number)
23245  ELSE
23250     PRINT "UNEXPECTED ERROR ";ERRM$;" OCCURED WHEN STORING FILE FOR TEST #
 ";Test_number
23255     PAUSE
23260  END IF
23265  RETURN
23270 !
23275 ! ============================================================
23280 ! NEW DISK
23285 ! ============================================================
23290 New_disk:!
23295  Last_test_num=Test_number
23300  Disc_requested=Disc_requested+1
23305  GOSUB Select_exit
23310  GCLEAR
23315  GOTO Top
23320          !
23325 ! ============================================================
23330 !   THE END
23335 ! ============================================================
23340 The_end:    !
23345  PRINTER IS 1
23350  DISP CHR$(129);"THAT'S ALL FOR NOW, RE-RUN PROGRAM IF NECESSARY";CHR$(128
)
23355  BEEP
23360  END
23365 !
23370 ! ============================================================
23375 !   FUNCTION I
23380 ! ============================================================
23385  DEF FNI(P1)
23390     S=1
23395     U=1
23400     V=0
23405     V=V+2
23410     U=U*P1^2/V^2
23415     S=S+U
23420     IF U>=S*2.E-8 THEN 23405
23425     RETURN S
23430  FNEND
```

```
10    !   PROGRAM: STATALYZE8
20    !
30    !   FOR USE WITH A HP9836 COMPUTER
40    !   USED TO READ STATISTICS ABOUT THE PROPELLER BLADE IMPACT TESTS
50    !   PERFORMED WITH THE M.V. ROBERT LEMEUR , DURING JUNE-JULY 1984.
60    !   THE PROGRAM READS IN THE 'STATSDISC' ( K7 ) DISC WHICH CONTAIN THE 343
70    !   DATA FILES MINS, MAXS, AND MEANS;
80    !   THE MIN AND MAX OF ALL THE MIN'S AND MAX'S; (NOT USED)
90    !   BLADE ORIENTATION , EVENT DURATION, INTERACTION ENERGY,
100   !   TYPE OF EVENT, RADIAL AND CIRC. LOCATION OF THE MAXIMUM BLADE FORCE,
110   !   AND; THE DIRECTION OF THE BLADE FORCE.
120   !   THIS PROGRAM ALSO CALCULATES TWO NEW ROWS OF DATA FOR EACH CHANNEL.
130   !   THE POSSIBLE CHANNELS ARE LISTED IN THE 'CHANNEL DESCRIPTIONS'.
140   !   THE COLUMNS OF DATA ARE LISTED IN THE 'COLUMN DESCRIPTIONS'.
150   !   X-Y PLOTS AND HISTOGRAM PLOTS ARE AVAILABLE WITH
160   !   THIS DATA.
170   !
180   OPTION BASE 1
190   DEG
200   !
210   !   WRITTEN BY: DOUG MONTGOMERY
220   !   DATE: AUGUST 21, 1984
230   !   VERSION NO: STATALYZE
240   !
250   !   MODIFIED BY:PAUL SPENCER
260   !   DATE:SEPT 05,1984
270   !   VERSION NO:STATALYZE2
280   !   REASON:TO INCLUDE CONDITIONAL TESTS ON DATA TO BE DISPLAYED
290   !
300   !   MODIFIED BY:KEN KIRBY
310   !   DATE:SEPT 18,1984
320   !   VERSION NO:STATALYZE2
330   !   REASON:TO CLARIFY INPUT STATEMENTS
340   !
350   !   MODIFIED BY:PAUL SPENCER
360   !   DATE:OCT 24 ,1984
370   !   VERSION NO:STATALYZE3
380   !   REASON:TO ALLOW PLOTTING OF ORIENTATION ,TIMING & ENERGY STATS
390   !
400   !   MODIFIED BY:SPENCER
410   !   DATE:NOV 13 ,1984
420   !   VERSION NO:STATALYZE4
430   !   REASON:TO ADD CHANNEL INFO PRINT OUT DURING CONDITIONAL INPUT
440   !
450   !   MODIFIED BY: KEN KIRBY
460   !   DATE: 84-12-12
470   !   VERSION NO: STATALYZE4
480   !   REASON: TO PUT IN A 'HELP' MANUAL
490   !           OUTPUT N/A FOR DATA POINTS OF -1.E6
500   !           GET RID OF EVENT DURATION TIMES = 0
510   !           CHANGE EVENT DURATION TIMES FROM 7 TO 6.81 SECONDS
520   !           FIX CURSOR DURING X-Y PLOTTING TO STOP PROGRAM FROM HANGING UP
530   !           ALLOW RE-PLOTTING OF FIGURES WITHOUT HAVING TO RE-ENTER
540   !           X-CHANNEL, Y-CHANNEL, AND CONDITONAL TEST DATA
550   !           BY JUST CHANGING THE SCALES.
560   !           SIMILARLY FOR HISTOGRAMS ; PUT IN A 'RE-PLOT' SOFT KEY
570   !           CALCULATE MEAN AND STANDARD DIVIATION OF HISTOGRAMS,
580   !           ASSUMING A NORMAL DISTRIBUTION ABOUT THE MEAN.
590   !
600   !   MODIFIED BY: KEN KIRBY
610   !   DATE: 85-01-14
620   !   VERSION NO: STATALYZE5
630   !   REASON: TO HANDLE TYPES OF INTERACTIONS AND INTERACTION NUMBERS
640   !
650   !   MODIFIED BY: KEN KIRBY
```

```
660  !   DATE: 85-01-28
670  !   VERSION NO: STATALYZE5
680  !   REASON: TO FIX SCALE LABLES FOR X AND Y AXES
690  !
700  !   MODIFIED BY: KEN KIRBY
710  !   DATE: 85-01-30
720  !   VERSION NO: STATALYZE6
730  !   REASON: TO CORRECT SLIDING BLOCK GAINS
740  !           AND TO GIVE EQUATION FOR BEST FIT LINE
750  !
760  !   MODIFIED BY: KEN KIRBY
770  !   DATE: 85-02-08
780  !   VERSION NO: STATALYZE6
790  !   REASON: TO PUT IN CHANNEL DESCRIPTIONS AND UNITS FOR CHANNEL # 30
800  !
810  !   MODIFIED BY: KEN KIRBY
820  !   DATE: 85-02-11
830  !   VERSION NO: STATALYZE7
840  !   REASON: TO REMOVE OFFSETS AND GAIN CORRECTIONS BECAUSE A NEW
850  !           STATDISK ,( DISK K7 ) WAS CREATED WHICH HAS THE PROPER
860  !           GAINS AND OFFSETS
870  !
880  !   MODIFIED BY: KEN KIRBY
890  !   DATE: 85-02-14
900  !   VERSION NO: STATALYZE7
910  !   REASON: TO MOVE CHANNEL DESIGNATIONS TO MATCH NEW STATDISC K7
920  !           AND ADD EVENT CHANNELS.
930  !
940  !   MODIFIED BY: KEN KIRBY
950  !   DATE: 85-02-21
960  !   VERSION NO: STATALYZE8
970  !   REASON: TO COMPUTE THE  MAX-MEAN & MIN-MEAN or DURATION FOR ALL DATA
980  !           AND ALLOW THEM TO BE PLOTTED AS SEPARATE CONDITIONS.
990  !
1000 !   MODIFIED BY:
1010 !   DATE:
1020 !   VERSION NO:
1030 !   REASON:
1040 !
1050  INTEGER Record_number,I,J,K
1060  REAL Stats_array(1:5,1:30,1:343)
1070  DIM Channel_desc$(1:30)[27]
1080  DIM Channel_sense$(1:30)[35]
1090  DIM Units$(1:30)[5]
1100  REAL X_point,Y_point
1110  INTEGER X_plot_type,Y_plot_type,Plot_type
1120  INTEGER Bins
1130  INTEGER X_bin(1:100)
1140  REAL Counts_per_bin
1150  REAL Xmax,Xmin,Ymax,Ymin,Xscale,Yscale
1160  DIM Max_min$(1:30,1:5)[14]
1170  DIM X_var$[6],Y_var$[6]
1180  INTEGER Test_result(10),Relational(10)
1190  INTEGER Cond_type(10),Cond_channel(10),Cond_type_2(10),Cond_channel_2(10)
1200  INTEGER Satisfy_list(343)
1210  REAL Comp_value(10)
1220  DIM Op$(1:6)[3]
1230  DATA " > "," < "," = "," > "," < "," = "
1240  READ Op$(*)
1250  DIM Temp_print$(3)[10]
1260 !
1270  Max_min$(1,1)="MIN VALUE "
1280  Max_min$(1,2)="MAX VALUE "
1290  Max_min$(1,3)="MEAN VALUE "
1300  Max_min$(1,4)="MIN-MEAN "
1310  Max_min$(1,5)="MAX-MEAN "
```

```
1320  FOR I=2 TO 10
1330     FOR J=1 TO 5
1340        Max_min$(I,J)=Max_min$(1,J)
1350     NEXT J
1360  NEXT I
1370  Max_min$(11,1)="RADIAL LOC. "
1380  Max_min$(11,2)="CIRC. LOC. "
1390  Max_min$(11,3)="FORCE SENSE "
1400  Max_min$(11,4)=""
1410  Max_min$(11,5)=""
1420  FOR I=12 TO 13
1430     FOR J=1 TO 5
1440        Max_min$(I,J)=Max_min$(1,J)
1450     NEXT J
1460  NEXT I
1470  Max_min$(14,1)="FIRST TYPE "
1480  Max_min$(14,2)="SECOND TYPE "
1490  Max_min$(14,3)="THIRD TYPE "
1500  Max_min$(14,4)=""
1510  Max_min$(14,5)=""
1520  Max_min$(15,1)="INTERRUPT # "
1530  Max_min$(15,2)="ICE or WATER "
1540  Max_min$(15,3)="SHIP DIRECT. "
1550  Max_min$(15,4)=""
1560  Max_min$(15,5)=""
1570  FOR I=16 TO 22
1580     FOR J=1 TO 5
1590        Max_min$(I,J)=Max_min$(1,J)
1600     NEXT J
1610  NEXT I
1620  Max_min$(23,1)="START ORIENT. "
1630  Max_min$(23,2)="PEAK ORIENT. "
1640  Max_min$(23,3)="DURATION "
1650  Max_min$(23,4)=""
1660  Max_min$(23,5)=""
1670  Max_min$(24,1)="INT. ENERGY "
1680  Max_min$(24,2)="DURATION TIME "
1690  Max_min$(24,3)="BL.FORCE AREA "
1700  Max_min$(24,4)="IPI POWER kW "
1710  Max_min$(24,5)=""
1720  Max_min$(25,1)="START TIME "
1730  Max_min$(25,2)="PEAK TIME "
1740  Max_min$(25,3)="END TIME "
1750  Max_min$(25,4)="PEAK-START "
1760  Max_min$(25,5)="DURATION "
1770  Max_min$(26,1)="START THRUST "
1780  Max_min$(26,2)="PEAK THRUST "
1790  Max_min$(26,3)="END THRUST "
1800  Max_min$(26,4)="PEAK-START "
1810  Max_min$(26,5)="END-PEAK "
1820  Max_min$(27,1)="START TORQUE "
1830  Max_min$(27,2)="PEAK TORQUE "
1840  Max_min$(27,3)="END TORQUE "
1850  Max_min$(27,4)="PEAK-START "
1860  Max_min$(27,5)="END-PEAK "
1870  Max_min$(28,1)="START TIME "
1880  Max_min$(28,2)="PEAK TIME "
1890  Max_min$(28,3)="END TIME "
1900  Max_min$(28,4)="PEAK-START "
1910  Max_min$(28,5)="DURATION "
1920  Max_min$(29,1)="START THRUST "
1930  Max_min$(29,2)="PEAK THRUST "
1940  Max_min$(29,3)="END THRUST "
1950  Max_min$(29,4)="PEAK-START "
1960  Max_min$(29,5)="END-PEAK "
1970  Max_min$(30,1)="START TORQUE "
```

```
1980  Max_min$(30,2)="PEAK TORQUE "
1990  Max_min$(30,3)="END TORQUE "
2000  Max_min$(30,4)="PEAK-START "
2010  Max_min$(30,5)="END-PEAK "
2020  !
2030  Channel_desc$(1)="BLADE CENTRE BENDING"
2040  Channel_desc$(2)="BLADE TRAILING EDGE TORQUE"
2050  Channel_desc$(3)="BLADE LEADING EDGE BENDING"
2060  Channel_desc$(4)="BLADE CENTRE TORQUE"
2070  Channel_desc$(5)="BLADE TRAILING EDGE BENDING"
2080  Channel_desc$(6)="BLADE LEADING EDGE TORQUE"
2090  Channel_desc$(7)="SLIDING BLOCK FORCE"
2100  Channel_desc$(8)="SHAFT THRUST"
2110  Channel_desc$(9)="SHAFT TORQUE"
2120  Channel_desc$(10)="SERVO OIL PRESSURE"
2130  Channel_desc$(11)="LOC. and DIR. OF MAX FORCE"
2140  Channel_desc$(12)="AFT TOP PROBE"
2150  Channel_desc$(13)="FUEL RACK"
2160  Channel_desc$(14)="TYPE OF INTERACTION"
2170  Channel_desc$(15)="INTER.#, ICE or WATER, DIR."
2180  Channel_desc$(16)="PROPELLER PITCH"
2190  Channel_desc$(17)="SHIP SPEED"
2200  Channel_desc$(18)="RUDDER ANGLE"
2210  Channel_desc$(19)="BLADE BENDING MOMENT"
2220  Channel_desc$(20)="BLADE SPINDLE TORQUE"
2230  Channel_desc$(21)="BLADE FORCE"
2240  Channel_desc$(22)="SHAFT SPEED"
2250  Channel_desc$(23)="BLADE START PEAK & DURATION"
2260  Channel_desc$(24)="TQ.ENG.&DUR.;F.AREA;IPI;PWR"
2270  Channel_desc$(25)="THRUST ST. PK. & END TIME"
2280  Channel_desc$(26)="THRUST ST. PK. & END THRUST"
2290  Channel_desc$(27)="THRUST ST. PK. & END TORQUE"
2300  Channel_desc$(28)="TORQUE ST. PK. & END TIME"
2310  Channel_desc$(29)="TORQUE ST. PK. & END THRUST"
2320  Channel_desc$(30)="TORQUE ST. PK. & END TORQUE"
2330  !
2340  Units$(1)=" MPa"
2350  Units$(2)=" MPa"
2360  Units$(3)=" MPa"
2370  Units$(4)=" MPa"
2380  Units$(5)=" MPa"
2390  Units$(6)=" MPa"
2400  Units$(7)=" kN"
2410  Units$(8)=" kN"
2420  Units$(9)=" kN.m"
2430  Units$(10)=" bar"
2440  Units$(11)=" m"
2450  Units$(12)=" mm"
2460  Units$(13)=" mm"
2470  Units$(14)=" "
2480  Units$(15)=" "
2490  Units$(16)=" deg"
2500  Units$(17)=" m/s"
2510  Units$(18)=" deg"
2520  Units$(19)=" kN.m"
2530  Units$(20)=" kN.m"
2540  Units$(21)=" kN"
2550  Units$(22)=" rpm"
2560  Units$(23)=" deg"
2570  Units$(24)=" "
2580  Units$(25)=" s"
2590  Units$(26)=" kN"
2600  Units$(27)=" kN.m"
2610  Units$(28)=" s"
2620  Units$(29)=" kN"
2630  Units$(30)=" kN.m"
```

```
2640  !
2650   Channel_sense$(1)="POS SIG FOR TIP BENDING FORWARD"
2660   Channel_sense$(2)="POS SIG FOR TRAIL. EDGE BENDING FWD"
2670   Channel_sense$(3)="POS SIG FOR TIP BENDING FORWARD"
2680   Channel_sense$(4)="POS SIG FOR TRAIL. EDGE BENDING FWD"
2690   Channel_sense$(5)="POS SIG FOR TIP BENDING FORWARD"
2700   Channel_sense$(6)="POS SIG FOR TRAIL. EDGE BENDING FWD"
2710   Channel_sense$(7)="POS SIG FOR TRAIL. EDGE BENDING FWD"
2720   Channel_sense$(8)="POS SIG IS SHAFT IN TENSION"
2730   Channel_sense$(9)="POS SIG IS ENGINE DRIVING SHAFT"
2740   Channel_sense$(10)="POS CHANGE INCREASES PITCH ANGLE"
2750   Channel_sense$(11)="0=ROOT .945=TIP ;.691=LE 0=CL CIRC."
2760   Channel_sense$(12)="POS CHANGE ,INCREASING SEPARATION"
2770   Channel_sense$(13)="POS CHANGE ,INCREASING FUEL"
2780   Channel_sense$(14)="0=N/E;1=ISOLATED;2=MILL.;3=BLOCKAGE"
2790   Channel_sense$(15)="#;0=WATER,1=ICE;-1=AST,0=STOP,1=AHD"
2800   Channel_sense$(16)="POS SIGNAL ,AHEAD PITCH"
2810   Channel_sense$(17)="ABSOLUTE VALUE OF VELOCITY"
2820   Channel_sense$(18)="POS SIG IS STBD."
2830   Channel_sense$(19)="POS SIG FOR TIP BENDING FORWARD"
2840   Channel_sense$(20)="POS SIG FOR TRAIL. EDGE BENDING FWD"
2850   Channel_sense$(21)="POS SIG FOR TIP BENDING FORWARD"
2860   Channel_sense$(22)="ALWAYS POSITIVE"
2870   Channel_sense$(23)="0 DEG. TOP 90 IS INBOARD, SINGLE BL"
2880   Channel_sense$(24)="INT. ENEG kJ;DUR. s;FORCE AREA kNs"
2890   Channel_sense$(25)="THRUST EVENT, AUTO. CHOOSEN"
2900   Channel_sense$(26)="THRUST EVENT, AUTO. CHOOSEN"
2910   Channel_sense$(27)="THRUST EVENT, AUTO. CHOOSEN"
2920   Channel_sense$(28)="TORQUE EVENT, AUTO. CHOOSEN"
2930   Channel_sense$(29)="TORQUE EVENT, AUTO. CHOOSEN"
2940   Channel_sense$(30)="TORQUE EVENT, AUTO. CHOOSEN"
2950  !
2960   PRINTER IS 1
2970   PRINT CHR$(12)
2980   GCLEAR
2990   BEEP
3000   Inpt$=""
3010   OFF KNOB
3020   GOSUB Instructions
3030   Running=0
3040   GOTO Help
3050 Beginning:  !
3060   DISP ""
3070   Running=1
3080   GOSUB Read_array
3090 Above_main_keys:  !
3100   DISP "PICK A FUNCTION KEY .... ANY KEY ..... EVERYONE IS A WINNER"
3110   GOSUB Main_keys
3120  !
3130   Top_exit=0
3140 Top_loop:    !
3150   IF NOT Top_exit THEN Top_loop
3160  !
3170   DISP "THAT'S ALL FOR NOW , RE-RUN PROGRAM IF NECESSARY"
3180   BEEP
3190   STOP
3200  !
3210  ! ==========================================================
3220  !   TOP EXIT
3230  ! ==========================================================
3240 Top_exit:    !
3250   Top_exit=1
3260   RETURN
3270  !
3280  ! ==========================================================
3290  !   IDLE
```

```
3300  ! ============================================================
3310 Idle:     !
3320   RETURN
3330  !
3340  ! ============================================================
3350  !   INSTRUCTIONS
3360  ! ============================================================
3370 Instructions:     !
3380   PRINT CHR$(12)
3390   PRINT "WELCOME ......YOU ARE IN THE WONDERFUL WORLD OF 'HELP'."
3400   PRINT "THE MAIN PROGRAM IS ENTERED BY PRESSING THE 'EXIT' SOFT KEY."
3410   PRINT "THIS HELP FEATURE MAY BE ENTERED FROM THE MAIN PROGRAM BY"
3420   PRINT "PRESSING THE 'HELP' SOFT KET. PRESSING ANY OF THESE KEYS WILL"
3430   PRINT "GIVE HELP ON THE TOPIC SHOWN. PRESS THE SOFT KEY FOR THE FIRST"
3440   PRINT "CHOICE SHOWN ON EACH. THE SECOND CHOICE ( IF THERE IS ONE )IS"
3450   PRINT "OBTAINED BY HOLDING DOWN THE 'SHIFT' KEY WHILE PRESSING THE SOFT"
3460   PRINT "KEY. IN ORDER TO CHOOSE THE DEFAULT VALUE OR LAST VALUE USED FOR"
3470   PRINT "ANY INPUT, PRESS THE 'CONTINUE' KEY WHEN ASKED FOR INPUT."
3480   PRINT "THIS PROGRAM IS USED FOR VIEWING THE STATISTICS DISK ( K7 ),WHICH"
3490   PRINT "WAS MADE BY MANIPULATING THE 343 DATA DISKS RECORDED ON BOARD THE"
3500   PRINT "M.V. ROBERT LEMEUR DURING JUNE-JULY 1984 PROPELLER BLADE TESTS."
3510   PRINT "THE DATA CAN BE PROCESSED IN THE MAJOR FOLLOWING WAYS:"
3520   PRINT "  LISTING OF THE CHANNEL MAX, MIN, AND MEANS FOR EACH TEST;"
3530   PRINT "  PLOTTING OF HISTOGRAMS SUBJECT TO CONDITIONAL TESTS;"
3540   PRINT "  LISTING OF THE CHANNELS WHICH PASS THE CONDITIONAL TESTS, AND;"
3550   PRINT "  PLOTTING OF MIN-MEAN, PEAK-MEAN, EVENT DURATIONS or POWER."
3560   RETURN
3570  !
3580  ! ============================================================
3590  !   HELP DUMP GRAPHICAL OUTPUT TO PRINTER
3600  ! ============================================================
3610 Help_dump_graph:     !
3620   PRINT CHR$(12)
3630   PRINT "THE 'DUMP GRAPHICS' SOFT KEY IS USED TO PRINTOUT A HARD COPY"
3640   PRINT "OF THE PRESENT PLOT ON THE SCREEN. IN ADDITION TO THE GRAPHICAL"
3650   PRINT "OUTPUT, A LISTING OF ANY CRITERIA WHICH THE DATA WAS CHECKED"
3660   PRINT "AGAINST , IS PRINTED. THE RECOMMENDED OUTPUT DEVICE IS A"
3670   PRINT "'HP9876A' PRINTER."
3680   RETURN
3690  !
3700  ! ============================================================
3710  !   DUMP GRAPHICAL OUTPUT TO PRINTER
3720  ! ============================================================
3730 Dump_graphics:     !
3740   DUMP DEVICE IS 701
3750   DUMP GRAPHICS
3760   PRINTER IS 701
3770   GOSUB Condition_print
3780   PRINT CHR$(12)
3790   PRINTER IS 1
3800   RETURN
3810  ! ============================================================
3820  ! PRINT CONDITIONAL DATA
3830  ! ============================================================
3840 Condition_print: !
3850   PRINT
3860   PRINT TAB(5),"TOTAL NUMBER OF DATA POINTS PASSING TESTS IS:";Satisfy_sum
3870   IF Points_outside>0 THEN
3880      PRINT
3890      PRINT TAB(5),"NUMBER OF POINTS OUTSIDE PLOTTING AREA IS:";Points_outsi
de
3900   END IF
3910   IF Hist_flag THEN
3920      Hist_std$[1,6]=VAL$(Hist_std)
3930      Hist_mean$[1,6]=VAL$(Hist_mean)
3940      PRINT TAB(5),"THE MEAN OF THE DATA PASSING THE CONDITIONAL TESTS IS:";
```

```
Hist_mean$
3950        PRINT TAB(5),"AND ITS STANDARD DEVIATION IS:";Hist_std$
3960     END IF
3970     IF NOT Conditional THEN
3980        PRINT
3990        PRINT TAB(5),"ALL DATA USED"
4000     ELSE
4010        PRINT
4020        PRINT TAB(5),"DATA SATISFIED THE FOLLOWING TEST(S)"
4030        PRINT
4040        !
4050        FOR K=1 TO Number_of_comps
4060           IF K<>1 AND Bool=1 THEN PRINT TAB(5),"AND"
4070           IF K<>1 AND Bool=2 THEN PRINT TAB(5),"OR"
4080           PRINT TAB(5);
4090           IF Relational(K)>0 AND Relational(K)<4 THEN
4100              PRINT USING "K,#";Max_min$(Cond_channel(K),Cond_type(K))&" OF "&
Channel_desc$(Cond_channel(K))&Op$(Relational(K))
4110              PRINT USING "K";Comp_value(K),Units$(Cond_channel(K))
4120           ELSE
4130              PRINT USING "K,#";Max_min$(Cond_channel(K),Cond_type(K))&" OF "&
Channel_desc$(Cond_channel(K))&Op$(Relational(K))
4140              PRINT USING "K";Max_min$(Cond_channel_2(K),Cond_type_2(K))&" OF
"&Channel_desc$(Cond_channel_2(K))
4150           END IF
4160        NEXT K
4170        !
4180     END IF
4190     IF B<>0 AND A<>0 AND Square_fit THEN
4200        PRINT
4210        PRINT "Y = ";B;"*X + ";A
4220     END IF
4230     RETURN
4240   !
4250   ! ==========================================================
4260   ! HELP DISPLAY OF CHANNEL DESRIPTIONS
4270   ! ==========================================================
4280 Help_channel_de: !
4290    PRINT CHR$(12)
4300    PRINT "THE 'CHANNEL DESCRIPTIONS' SOFT KEY OUTPUTS A LISTING OF THE"
4310    PRINT "CHANNELS OF STATISTICS STORED ON DISK # K7. THE FIRST 22 CHANNELS"
4320    PRINT "OF DATA , EXCEPT # 11,14 and 15 ; HAVE THE RESPECTIVE MINIMUM,"
4330    PRINT "MAXIMUM AND MEANS ,WHICH ARE AVAILABLE, STORED FOR THEM."
4340    PRINT "THE DEFINITIONS USED FOR THE MIN ,MAX ,AND MEANS , ARE:"
4350    PRINT "  MINIMUM- THE VALUE CLOSEST TO NEGATIVE INFINITY;"
4360    PRINT "  MAXIMUM- THE VALUE CLOSEST TO POSITIVE INFINITY, AND ;"
4370    PRINT "  MEAN- OBTAINED BY ADDING ALL POINTS AND DIVIDING BY THE NUMBER"
4380    PRINT "        OF POINTS."
4390    PRINT
4400    PRINT "IN ADDITION TO THESE MIN, MAX AND MEANS; FOURTH AND FIFTH COLUMNS"
4410    PRINT "ARE CALCULATED WHICH HAVE THE MIN-MEAN, MAX-MEAN, EVENT POWER,"
4420    PRINT "RISE TIMES or EVENT DURATION."
4430    PRINT "SOME OF THE DATA IS NOT AVAILABLE BECAUSE OF SIGNAL RELIABILITY"
4440    PRINT "PROBLEMS, THESE ARE LISTED AS N/A. AS A CONSEQUENCE OF THIS, THE"
4450    PRINT "NUMBER OF USABLE DATA POINTS IS DIFFERENT FOR EACH CHANNEL."
4460    PRINT "THE SHIP SPEED SIGNAL IS ALWAYS POSITIVE WEATHER THE SHIP IS"
4470    PRINT "GOING AHEAD OR ASTERN. ALSO THE SPEED SIGNAL DOES NOT FUNCTION"
4480    PRINT "RELIABLY IN OPEN WATER OR BELOW .5 m/s."
4490    DISP "<<<<<<<<<<<<<<<<<< PRESS CONT FOR NEXT PAGE>>>>>>>>>>>>>>>>>>>>"
4500    PAUSE
4510    PRINT CHR$(12)
4520    DISP ""
4530    PRINT "THE MINIMUM , MAXIMUM , AND MEAN VALUES FOR THIS STATISTICS DISK"
4540    PRINT "ARE MORE ACCURATE THEN THE DISK WHICH IS READ BY THE 'STATALYZE6'"
4550    PRINT "PROGRAM. THIS IS BECAUSE THE GAINS WERE CORRECTED BEFORE THE MIN"
4560    PRINT "MAX and MEANS WERE FOUND. ALSO OFFSETS WERE ADDED TO THE SLIDING"
```

```
4570   PRINT "BLOCK SIGNAL. THE DATA USED BY THIS PROGRAM WAS ONLY ANALYZED UP"
4580   PRINT "TO THE NUMBER OF GOOD DATA POINTS WHICH EXIST IN THE RAW DATA"
4590   PRINT "THE RADIAL AND CIRC. LOCATIONS GIVEN IN CHANNEL 11 ARE FOR THE"
4600   PRINT "POINT OF MAXIMUM BLADE FORCE. WHICH WAS FOUND BY THE ANALYZE3_8"
4610   PRINT "PROGRAM."
4620   PRINT "THE DATA IN CHANNELS 14 AND 15 WAS ENTERED MANUALLY."
4630   DISP "<<<<<<<<<<<<<<<<<< PRESS CONT FOR NEXT PAGE>>>>>>>>>>>>>>>>>>>>"
4640   PAUSE
4650   PRINT CHR$(12)
4660   DISP ""
4670   PRINT "CHANNELS 23 and 24 WERE OBTAINED BY MANUALLY REVIEWING EACH EVENT"
4680   PRINT "AND DETERMINING THE ORIENTATION OF THE BLADE AT THE START OF THE"
4690   PRINT "EVENT, THE ORIENTATION OF THE BLADE AT THE PEAK OF THE EVENT ,THE"
4700   PRINT "NUMBER OF DEGREES THROUGH WHICH THE  BLADE ROTATED DURING THE"
4710   PRINT "PERTERBATION."
4720   PRINT "CHANNEL 24 DURATION TIME WAS MANUALLY ESTIMATED ,AND IS THE TIME"
4730   PRINT "IN SECONDS (UP TO THE WINDOW LIMIT OF 6.81 SECONDS) THAT THE ICE"
4740   PRINT "IS OR PARTIALLY BLOCKING THE NOZZLE."
4750   PRINT "CHANNEL 24 INTERACTION ENERGY WAS OBTAINED BY CALCULATING THE"
4760   PRINT "AREA UNDER THE TRANSIENT IN THE SHAFT TORQUE DATA AND SUBTRACTING"
4770   PRINT "THE STEADY-STATE AREA."
4780   PRINT "THE TORQUE AND THRUST EVENTS IN CHANNELS 25 TO 30 WERE FOUND BY"
4790   PRINT "THE 'ANALYZE3_8' PROGRAM."
4800   RETURN
4810   !
4820   ! =============================================================
4830   ! DISPLAY OF CHANNEL DESRIPTIONS
4840   ! =============================================================
4850 Channel_descrip: !
4860   Inpt$=""
4870   INPUT " DO YOU WANT A HARDCOPY ?: Y or CONT",Inpt$
4880   IF UPC$(Inpt$[1,1])="Y" THEN
4890     PRINTER IS 701
4900   ELSE
4910     GRAPHICS OFF
4920   END IF
4930   PRINT
4940   Chan_tab=2
4950   Des_tab=8
4960   Units_tab=35
4970   Sense_tab=45
4980   PRINT
4990   PRINT TAB(10);"DESCRIPTIONS OF CHANNELS OF DATA AVAILABLE ON THE STATISTI
CS"
5000   PRINT TAB(10);"DISK FOR THE MV ROBERT LEMEUR ICE-PROPELLER IMPACT TESTS"
5010   PRINT
5020   PRINT
5030   PRINT "CHAN#";TAB(Des_tab);"CHANNEL DESCRIPTIONS";TAB(Units_tab);"UNITS";
TAB(Sense_tab);"COMMENTS"
5040   PRINT
5050   FOR I=1 TO 30
5060     PRINT TAB(Chan_tab);I;TAB(Des_tab);Channel_desc$(I);TAB(Units_tab);Uni
ts$(I);TAB(Sense_tab);Channel_sense$(I)
5070   NEXT I
5080   IF UPC$(Inpt$[1,1])<>"Y" THEN
5090     DISP "PRESS 'CONT' TO RETURN TO MAIN PROGRAM"
5100     PAUSE
5110     PRINT CHR$(12)
5120     DISP ""
5130     GRAPHICS ON
5140   ELSE
5150     PRINT CHR$(12)
5160   END IF
5170   PRINTER IS 1
5180   RETURN
5190   !
```

```
5200  ! ==========================================================
5210  ! DISPLAY OF COLUMN DESRIPTIONS
5220  ! ==========================================================
5230 Column_descrip: !
5240   Inpt$=""
5250   INPUT " DO YOU WANT A HARDCOPY ?: Y or CONT",Inpt$
5260   IF UPC$(Inpt$[1,1])="Y" THEN
5270      PRINTER IS 701
5280   ELSE
5290      GRAPHICS OFF
5300   END IF
5310   PRINT
5320   PRINT TAB(10);"DESCRIPTIONS OF COLUMNS OF DATA AVAILABLE ON THE STATISTIC
S"
5330   PRINT TAB(10);"DISK FOR EACH CHANNEL OF DATA, FOR THE MV ROBERT LEMEUR"
5340   PRINT TAB(10);"ICE-PROPELLER IMPACT TESTS"
5350   PRINT
5360   PRINT
5370   PRINT "CHAN";TAB(30);"COLUMN DESCRIPTIONS";TAB(76);"UNITS"
5380   PRINT
5390   PRINT " #";TAB(9);"ONE";TAB(24);"TWO";TAB(38);"THREE";TAB(53);"FOUR";TAB(
68);"FIVE"
5400   PRINT
5410   FOR I=1 TO 30
5420      PRINT USING "DD,#";I
5430      FOR J=1 TO 5
5440         PRINT TAB(J*15-11);Max_min$(I,J);
5450      NEXT J
5460      PRINT TAB(76);Units$(I)
5470   NEXT I
5480   IF UPC$(Inpt$[1,1])<>"Y" THEN
5490      DISP "PRESS 'CONT' TO RETURN TO MAIN PROGRAM"
5500      PAUSE
5510      PRINT CHR$(12)
5520      DISP ""
5530      GRAPHICS ON
5540   ELSE
5550      PRINT CHR$(12)
5560   END IF
5570   PRINTER IS 1
5580   RETURN
5590   !
5600  ! ==========================================================
5610  ! HELP DISPLAY OF THE DATA CONTAINED IN A PARTICULAR EVENT
5620  ! ==========================================================
5630 Help_list_data: !
5640   PRINT CHR$(12)
5650   PRINT "LISTS ALL OF THE AVAILABLE STATISTIAL DATA FOR ANY EVENT CHOOSEN."
5660   RETURN
5670   !
5680  ! ==========================================================
5690  ! DISPLAY OF THE DATA CONTAINED IN A PARTICULAR EVENT
5700  ! ==========================================================
5710 List_data: !
5720   Inpt$=""
5730   INPUT " DO YOU WANT A HARDCOPY? : Y or CONT",Inpt$
5740   IF UPC$(Inpt$[1,1])="Y" THEN
5750      PRINTER IS 701
5760   ELSE
5770      GRAPHICS OFF
5780   END IF
5790 Re_enter_l_n:!
5800   INPUT "ENTER THE EVENT NUMBER YOU WANT DIPLAYED:",L_n
5810   IF L_n<1 OR L_n>343 THEN
5820      DISP "RE-";
5830      BEEP
```

```
5840        GOTO Re_enter_1_n
5850     END IF
5860     PRINT
5870     PRINT TAB(5);"DATA FOR EVENT NUMBER : ";L_n
5880     PRINT
5890     PRINT " #          CHANNEL                                COL 1     COL 2    COL
3    UNITS"
5900     PRINT
5910 P_list_2:IMAGE 2D,2A,35A,3(10A),2A,6A
5920    FOR K=1 TO 30
5930       FOR I=1 TO 3
5940          IF Stats_array(I,K,L_n)=-1.E+6 THEN
5950             Temp_print$(I)[1,10]="    N/A   "
5960          ELSE
5970             Temp_print$(I)[1,10]=VAL$(INT((Stats_array(I,K,L_n)*100))/100)
5980             IF POS(Temp_print$(I),".")=0 THEN
5990                Start_pos=7-LEN(VAL$(INT((Stats_array(I,K,L_n)*100))/100))
6000             ELSE
6010                Start_pos=8-POS(Temp_print$(I),".")
6020             END IF
6030             Start_pos=MAX(1,Start_pos)
6040             Temp_print$(I)[1,10]="          "
6050             Temp_print$(I)[Start_pos,10]=VAL$(INT((Stats_array(I,K,L_n)*100)
)/100)
6060          END IF
6070       NEXT I
6080       PRINT USING P_list_2;K," ",Channel_desc$(K),Temp_print$(1),Temp_print$
(2),Temp_print$(3),"  ",Units$(K)
6090    NEXT K
6100 !
6110    PRINT
6120    PRINT TAB(5);" N/A - MEANS 'NO DATA AVAILABLE'"
6130    IF UPC$(Inpt$[1,1])<>"Y" THEN
6140       DISP "PRESS 'CONT' TO RETURN TO MAIN PROGRAM"
6150       PAUSE
6160       DISP ""
6170       PRINT CHR$(12)
6180       GRAPHICS ON
6190    ELSE
6200       PRINT CHR$(12)
6210    END IF
6220    PRINTER IS 1
6230    RETURN
6240    !
6250  ! ==========================================================
6260  ! HELP LIST OF EVENTS WHICH PASS CONDITIONAL TEST(S)
6270  ! ==========================================================
6280 Help_accept_lis: !
6290    PRINT CHR$(12)
6300    PRINT "LISTS THE EVENT NUMBERS WHOSE DATA SATISFIES THE CONDITIONAL"
6310    PRINT "TESTS. NO NUMBER PRINTED SIGNIFIES THAT EITHER THE CONDITIONAL"
6320    PRINT "TEST WAS FAILED, OR THAT INVALID DATA OCCURED IN EITHER X or (Y)"
6330    PRINT "or IN THE DATA USED IN THE CONDITIONAL TEST."
6340    RETURN
6350    !
6360  ! ==========================================================
6370  ! LIST OF EVENTS WHICH PASS CONDITIONAL TEST(S)
6380  ! ==========================================================
6390 Accept_list: !
6400    Inpt$=""
6410    INPUT "DO YOU WANT HARDCOPY ?: Y or CONT",Inpt$
6420    IF UPC$(Inpt$[1,1])="Y" THEN
6430       PRINTER IS 701
6440    ELSE
6450       GRAPHICS OFF
6460    END IF
```

```
6470    PRINT
6480    IF Hist_flag THEN
6490       PRINT USING "K";Max_min$(X_channel,X_plot_type);" OF ";Channel_desc$(X
_channel);Units$(X_channel);" HISTOGRAM"
6500    ELSE
6510       PRINT " X VERSES Y PLOT DATA WITH THE FOLLOWING AXIS :"
6520       PRINT
6530       PRINT USING "K";"X CHANNEL IS : ";Max_min$(X_channel,X_plot_type);" OF
 ";Channel_desc$(X_channel);Units$(X_channel)
6540       PRINT USING "K";"Y CHANNEL IS : ";Max_min$(Y_channel,Y_plot_type);" OF
 ";Channel_desc$(Y_channel);Units$(Y_channel)
6550    END IF
6560    PRINT
6570    PRINT " LIST OF DATA POINTS WHICH PASS CONDITIONAL TEST"
6580    PRINT
6590    FOR I=1 TO 343
6600       IF Satisfy_list(I)=1 THEN PRINT TAB(5+5*(I MOD 10)),I;
6610       IF I MOD 10=9 THEN PRINT CHR$(13)
6620    NEXT I
6630    PRINT
6640    GOSUB Condition_print
6650    IF UPC$(Inpt$[1,1])="Y" THEN
6660       PRINT CHR$(12)
6670       PRINTER IS 1
6680    ELSE
6690       DISP "PRESS 'CONT' TO RETURN TO MAIN PROGRAM"
6700       PAUSE
6710       DISP ""
6720       PRINT CHR$(12)
6730       GRAPHICS ON
6740    END IF
6750    RETURN
6760    !
6770    ! ============================================================
6780    !    HELP LEAST SQUARE FIT OF X-Y DATA
6790    ! ============================================================
6800 Help_least_fit:     !
6810    PRINT CHR$(12)
6820    PRINT "A LEAST SQUARE FIT IS CALCULATED USING ALL DATA THAT PASSES THE"
6830    PRINT "CONDITIONAL TESTS. THIS LINE IS PLOTTED ON THE X-Y GRAPH AND THE"
6840    PRINT "EQUATION OF THE FITTED LINE IS GIVEN IN THE HARD COPY OUTPUT."
6850    RETURN
6860    !
6870    ! ============================================================
6880    !    LEAST SQUARE FIT OF X-Y DATA
6890    ! ============================================================
6900 Least_fit:     !
6910    IF NOT Square_fit THEN RETURN
6920    N=0
6930    Sum_x=0
6940    Sum_y=0
6950    Sum_x_y=0
6960    Sum_x_2=0
6970    FOR I=1 TO 343
6980       X_point=Stats_array(X_plot_type,X_channel,I)
6990       Y_point=Stats_array(Y_plot_type,Y_channel,I)
7000       IF X_point<>-1.E+6 AND Y_point<>-1.E+6 THEN
7010          GOSUB Condition_test
7020          IF Satisfy THEN
7030             Sum_y=Sum_y+Y_point
7040             Sum_x=Sum_x+X_point
7050             Sum_x_y=Sum_x_y+X_point*Y_point
7060             Sum_x_2=Sum_x_2+X_point*X_point
7070             N=N+1
7080          END IF
7090       END IF
```

```
7100    NEXT I
7110    Delta=N*Sum_x_2-Sum_x*Sum_x
7120    A=1/Delta*(Sum_y*Sum_x_2-Sum_x_y*Sum_x)
7130    B=1/Delta*(N*Sum_x_y-Sum_x*Sum_y)
7140    MOVE Xmin,A+B*Xmin
7150    DRAW Xmax,A+B*Xmax
7160    DISP "Y= ";B;"*X + ";A
7170    RETURN
7180  !
7190  ! ==========================================================
7200  !    READ ARRAY FROM DISC
7210  ! ==========================================================
7220 Read_array:       !
7230    PRINT CHR$(12)
7240    GRAPHICS OFF
7250    MAT Stats_array= (-1.E+6)
7260    BEEP
7270    PRINT
7280    PRINT "PLACE DISC WITH ALL THE MIN'S AND MAX'S INTO THE RIGHT DRIVE"
7290    PRINT "( DISK # K7 ) ; AND PUSH 'CONT'"
7300    PAUSE
7310    DISP "READING DISK .... AND MANIPULATING DATA .... HOLD ON"
7320    ALLOCATE Temp_array(3,30,343)
7330    ASSIGN @Array_file TO "STATSDISC:INTERNAL,4,0"
7340    ENTER @Array_file;Temp_array(*)
7350    ASSIGN @Array_file TO *
7360    FOR I=1 TO 3
7370       FOR J=1 TO 30
7380          FOR K=1 TO 343
7390             Stats_array(I,J,K)=Temp_array(I,J,K)
7400          NEXT K
7410       NEXT J
7420    NEXT I
7430    DEALLOCATE Temp_array(*)
7440    GOSUB Calculate
7450    PRINT CHR$(12),CHR$(131)
7460    PRINT "YOU HAVE ENTERED INTO THE RELM OF 'STATALYZE8',ADVENTURE"
7470    PRINT "AWAITS THOSE WHO ARE BRAVE ENOUGH TO CONTINUE>>>>>>>>>>>"
7480    PRINT CHR$(128)
7490    DISP "PICK A KEY...ANY KEY...EVERYONE IS A WINNER"
7500    GRAPHICS ON
7510    RETURN
7520  !
7530  ! ==========================================================
7540  ! CALCULATE
7550  ! ==========================================================
7560 Calculate: !
7570    DISP "CALCULATING EXTRA COLUMNS .... HOLD ON"
7580    FOR K=1 TO 343
7590       FOR J=1 TO 10
7600          IF Stats_array(3,J,K)<>-1.E+6 THEN
7610             IF Stats_array(1,J,K)<>-1.E+6 THEN
7620                Stats_array(4,J,K)=Stats_array(1,J,K)-Stats_array(3,J,K)
7630             END IF
7640             IF Stats_array(2,J,K)<>-1.E+6 THEN
7650                Stats_array(5,J,K)=Stats_array(2,J,K)-Stats_array(3,J,K)
7660             END IF
7670          END IF
7680       NEXT J
7690       FOR J=12 TO 13
7700          IF Stats_array(3,J,K)<>-1.E+6 THEN
7710             IF Stats_array(1,J,K)<>-1.E+6 THEN
7720                Stats_array(4,J,K)=Stats_array(1,J,K)-Stats_array(3,J,K)
7730             END IF
7740             IF Stats_array(2,J,K)<>-1.E+6 THEN
7750                Stats_array(5,J,K)=Stats_array(2,J,K)-Stats_array(3,J,K)
```

```
7760          END IF
7770        END IF
7780      NEXT J
7790      FOR J=16 TO 22
7800        IF Stats_array(3,J,K)<>-1.E+6 THEN
7810          IF Stats_array(1,J,K)<>-1.E+6 THEN
7820            Stats_array(4,J,K)=Stats_array(1,J,K)-Stats_array(3,J,K)
7830          END IF
7840          IF Stats_array(2,J,K)<>-1.E+6 THEN
7850            Stats_array(5,J,K)=Stats_array(2,J,K)-Stats_array(3,J,K)
7860          END IF
7870        END IF
7880      NEXT J
7890      IF Stats_array(1,24,K)<>-1.E+6 AND Stats_array(2,24,K)<>-1.E+6 THEN
7900        IF Stats_array(2,24,K)<>0 THEN
7910          Stats_array(4,24,K)=Stats_array(1,24,K)/Stats_array(2,24,K)
7920        END IF
7930      END IF
7940      FOR J=25 TO 28 STEP 3
7950        IF Stats_array(1,J,K)<>-1.E+6 THEN
7960          IF Stats_array(2,J,K)<>-1.E+6 THEN
7970            Stats_array(4,J,K)=Stats_array(2,J,K)-Stats_array(1,J,K)
7980          END IF
7990          IF Stats_array(3,J,K)<>-1.E+6 THEN
8000            Stats_array(5,J,K)=Stats_array(3,J,K)-Stats_array(1,J,K)
8010          END IF
8020        END IF
8030      NEXT J
8040      FOR J=26 TO 29 STEP 3
8050        IF Stats_array(2,J,K)<>-1.E+6 THEN
8060          IF Stats_array(1,J,K)<>-1.E+6 THEN
8070            Stats_array(4,J,K)=Stats_array(2,J,K)-Stats_array(1,J,K)
8080          END IF
8090          IF Stats_array(3,J,K)<>-1.E+6 THEN
8100            Stats_array(5,J,K)=Stats_array(3,J,K)-Stats_array(2,J,K)
8110          END IF
8120        END IF
8130      NEXT J
8140      FOR J=27 TO 30 STEP 3
8150        IF Stats_array(2,J,K)<>-1.E+6 THEN
8160          IF Stats_array(1,J,K)<>-1.E+6 THEN
8170            Stats_array(4,J,K)=Stats_array(2,J,K)-Stats_array(1,J,K)
8180          END IF
8190          IF Stats_array(3,J,K)<>-1.E+6 THEN
8200            Stats_array(5,J,K)=Stats_array(3,J,K)-Stats_array(2,J,K)
8210          END IF
8220        END IF
8230      NEXT J
8240    NEXT K
8250    RETURN
8260    !
8270   ! ============================================================
8280   !    HELP HISTOGRAM
8290   ! ============================================================
8300 Help_histogram:      !
8310    PRINT CHR$(12)
8320    PRINT "THE MEAN AND STANDARD DEVIATION OF THE DATA WHICH PASSES THE"
8330    PRINT "CONDITIONAL TESTS IS CALCULATED AND GIVEN IN THE HARD COPY."
8340    PRINT "THE NUMBER OF DATA POINTS WHICH PASS THE CONDITIONAL TESTS"
8350    PRINT "AND ARE OUTSIDE OF THE PLOTTING RANGE IS LISTED ON THE SREEN"
8360    PRINT "AND IN THE HARD COPY."
8370    RETURN
8380   !
8390   ! ============================================================
8400   !    HELP RE-HISTOGRAM
8410   ! ============================================================
8420 Help_re_hist:    !
8430   PRINT CHR$(12)
8440   PRINT "THIS IS FOR RE-PLOTTING THE HISTOGRAM WITHOUT HAVING TO RE-ENTER"
8450   PRINT "THE CHANNEL #,CHANNEL DESCRIPTION, or CONDITIONAL TEST DATA."
8460   PRINT "THIS ROUTINE DOES ALLOW YOU TO CHANGE THE HORIZONTAL AND VERTICAL"
8470   PRINT "SCALES."
8480   RETURN
8490   !
8500   ! ============================================================
8510   !    HISTOGRAM
8520   ! ============================================================
8530 Histogram:     !
8540   GRAPHICS OFF
8550   Square_fit=0
8560 Re_enter_id:INPUT "ENTER: HISTOGRAM DATA IDENTIFIER CHANNEL & COLUMN : 1-30
, 1-5",X_channel,X_plot_type
8570   IF X_channel=34 THEN X_channel=22
8580   IF X_channel<1 OR X_channel>30 OR X_plot_type<1 OR X_plot_type>5 THEN
8590     BEEP
8600     DISP "RE-";
8610     GOTO Re_enter_id
8620   END IF
8630   !
8640   GOSUB Condition_input
8650   Xmax=-20000
8660   Xmin=20000
8670   Satisfy_sum=0
8680   MAT Satisfy_list= (0)
8690   Hist_sum=0
8700   Hist_sum_sq=0
8710   FOR I=1 TO 343
8720     IF Stats_array(X_plot_type,X_channel,I)<>-1.E+6 THEN
8730       GOSUB Condition_test
8740       IF Satisfy THEN
8750         Satisfy_sum=Satisfy_sum+1
8760         Satisfy_list(I)=1
8770         Xmax=MAX(Xmax,Stats_array(X_plot_type,X_channel,I))
8780         Xmin=MIN(Xmin,Stats_array(X_plot_type,X_channel,I))
8790         Hist_sum=Hist_sum+Stats_array(X_plot_type,X_channel,I)
8800         Hist_sum_sq=Hist_sum_sq+Stats_array(X_plot_type,X_channel,I)*Sta
ts_array(X_plot_type,X_channel,I)
8810       END IF
8820     END IF
8830   NEXT I
8840   Data_x_max=Xmax
8850   Data_x_min=Xmin
8860   IF Satisfy_sum THEN
8870     Hist_mean=Hist_sum/Satisfy_sum
8880     Hist_std_temp=(Hist_sum_sq/Satisfy_sum-Hist_mean*Hist_mean)
8890     IF Hist_std_temp<0 THEN
8900       Hist_std=0
8910     ELSE
8920       Hist_std=SQR(Hist_std_temp)
8930     END IF
8940   END IF
8950 Re_histogram:  !
8960   Hist_flag=1
8970   Points_outside=0
8980   GRAPHICS OFF
8990   GINIT
9000   GRAPHICS ON
9010   GCLEAR
9020   OFF KNOB
9030   LORG 5
9040   CSIZE 3.3
9050   PRINT USING "K";"HISTOGRAM DATA IS : ";Max_min$(X_channel,X_plot_type)&"
```

```
OF "&Channel_desc$(X_channel)&Units$(X_channel)
9060    PRINT "DATA MINIMUM X = ";Data_x_min;"   PLOT MINIMUM X VALUE IS: ";Xmin
9070    PRINT "DATA MAXIMUM X = ";Data_x_max;"   PLOT MAXIMUM X VALUE IS: ";Xmax
9080 Re_input_lim:INPUT "ENTER HISTOGRAM LIMIT VALUES FOR : Xmin , Xmax",Xmin,Xm
ax
9090    PRINT "HISTOGRAM X RANGE IS: ";Xmax-Xmin
9100 Re_input_bins:INPUT "ENTER HOW MANY BINS TO PUT THE DATA INTO : Bins",Bins
9110    IF Bins<1 OR Bins>100 THEN
9120       BEEP
9130       DISP "RE-";
9140       GOTO Re_input_bins
9150    END IF
9160    Alternate=1
9170    FOR K=1 TO 9
9180       IF Bins>10*K THEN Alternate=K+1
9190    NEXT K
9200    IF Xmax<Xmin THEN
9210       Temp=Xmax
9220       Xmax=Xmin
9230       Xmin=Temp
9240    END IF
9250    Xscale=Xmax-Xmin
9260    Counts_per_bin=Xscale/Bins
9270    MAT X_bin= (0)
9280    Ymax=0
9290    Ymin=0
9300    FOR I=1 TO 343
9310       X_point=Stats_array(X_plot_type,X_channel,I)
9320       IF X_point<>-1.E+6 THEN
9330          IF Satisfy_list(I)<>0 THEN
9340             IF X_point<Xmin OR X_point>Xmax THEN
9350                Points_outside=Points_outside+1
9360             ELSE
9370                X_value=INT((X_point-Xmin)/Counts_per_bin)+1
9380                X_bin(X_value)=X_bin(X_value)+1
9390                Ymax=MAX(Ymax,X_bin(X_value))
9400             END IF
9410          END IF
9420       END IF
9430    NEXT I
9440    Ymax_temp=Ymax
9450    PRINT "MAXIMUM BIN COUNT VALUE IS: ";Ymax
9460    PRINT "NUMBER OF DATA POINTS PASSING TESTS IS:";Satisfy_sum
9470    PRINT "NUMBER OF DATA POINST OUTSIDE RANGE IS:";Points_outside
9480 Re_enter_y_max:INPUT "ENTER MAXIMUM DESIRED BIN PLOT VALUE : Ymax",Ymax
9490    IF Ymax<=Ymax_temp THEN
9500       BEEP
9510       DISP "RE-";
9520       GOTO Re_enter_y_max
9530    END IF
9540    Yscale=Ymax-Ymin
9550    VIEWPORT 15,125,13,90
9560    PRINT CHR$(12)
9570    FRAME
9580    WINDOW Xmin,Xmax,Ymin,Ymax
9590    Y_major=1
9600    IF Yscale>10 THEN Y_major=2
9610    IF Yscale>20 THEN Y_major=5
9620    IF Yscale>50 THEN Y_major=10
9630    IF Yscale>100 THEN Y_major=20
9640    IF Yscale>200 THEN Y_major=50
9650    AXES Counts_per_bin,Y_major,Xmin,Ymin,1,5,3
9660    CLIP OFF
9670    LDIR 0
9680    MOVE Xmin+Xscale/2,Ymax+.05*Yscale
9690    LABEL "ROBERT LEMEUR TEST PERIOD DATA - 1984"
```

CANADIAN
MARINE
DRILLING
LIMITED

MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE:
"STATALYZE 8"

APPENDIX A

```
9700   LDIR 90
9710   MOVE Xmin-.1*Xscale,Ymin+Yscale/2
9720   LABEL "COUNTS"
9730   LDIR 0
9740   MOVE Xmin+Xscale/2,Ymin-.10*Yscale
9750   LABEL USING "K";Max_min$(X_channel,X_plot_type)&" OF "&Channel_desc$(X_ch
annel)&Units$(X_channel)
9760   FOR L=Xmin TO Xmax STEP Counts_per_bin*Alternate
9770      IF ABS(L)<.00001 THEN L=0
9780      MOVE L,Ymin-.05*Yscale
9790      LABEL L
9800   NEXT L
9810   FOR L=Ymin TO Ymax STEP Y_major
9820      IF ABS(L)<.00001 THEN L=0
9830      MOVE Xmin-.05*Xscale,L
9840      LABEL L
9850   NEXT L
9860   CLIP ON
9870   FOR I=1 TO Bins
9880      MOVE Xmin+(I-1)*Counts_per_bin,0
9890      DRAW Xmin+(I-1)*Counts_per_bin,X_bin(I)
9900      DRAW Xmin+I*Counts_per_bin,X_bin(I)
9910      DRAW Xmin+I*Counts_per_bin,0
9920   NEXT I
9930   RETURN
9940   !
9950   ! ============================================================
9960   !    HELP X-Y PLOT
9970   ! ============================================================
9980 Help_x_y_plot:     !
9990   PRINT CHR$(12)
10000  PRINT "THE X-Y PLOTTING ROUTINE ALLOWS THE PLOTTING OF ANY CHANNEL"
10010  PRINT "OF DATA VERSES ANY OTHER CHANNEL, SUBJECT TO CONDITIONAL"
10020  PRINT "TESTS WHICH ARE SPECIFIED BY THE USER."
10030  PRINT "THE NUMBER OF DATA POINTS WHICH PASS THE CONDITIONAL TESTS"
10040  PRINT "AND ARE OUTSIDE OF THE PLOTTING RANGE IS LISTED ON THE CRT"
10050  PRINT "AND IN THE HARD COPY."
10060  RETURN
10070 !
10080 ! ============================================================
10090 !    HELP RE-X-Y PLOT
10100 ! ============================================================
10110 Help_re_x_y_pl:    !
10120  PRINT CHR$(12)
10130  PRINT "THIS IS FOR RE-PLOTTING THE X-Y PLOTS WITHOUT HAVING TO RE-ENTER"
10140  PRINT "THE CHANNEL #,CHANNEL DESCRIPTION, or CONDITIONAL TEST DATA."
10150  PRINT "THIS ROUTINE DOES ALLOW YOU TO CHANGE THE HORIZONTAL AND VERTICAL"
10160  PRINT "SCALES."
10170  RETURN
10180 !
10190 ! ============================================================
10200 !    X-Y PLOT
10210 ! ============================================================
10220 X_y_plot:    !
10230  GRAPHICS OFF
10240  Hist_flag=0
10250  Square_fit=1
10260 Re_input_ident:INPUT "ENTER X AXIS DATA IDENTIFIER CHANNEL & COLUMN: 1-30,
1-5",X_channel,X_plot_type
10270  IF X_channel=34 THEN X_channel=22
10280  IF X_channel<1 OR X_channel>30 OR X_plot_type<1 OR X_plot_type>5 THEN
10290     BEEP
10300     DISP "RE-";
10310     GOTO Re_input_ident
10320  END IF
10330  !
```

```
10340 Re_enter_y_chan:INPUT "ENTER Y AXIS DATA IDENTIFIER CHANNEL & COLUMN: 1-30
,1-5",Y_channel,Y_plot_type
10350   IF Y_channel=34 THEN Y_channel=22
10360   IF Y_channel<1 OR Y_channel>30 OR Y_plot_type<1 OR Y_plot_type>5 THEN
10370     BEEP
10380     DISP "RE-";
10390     GOTO Re_enter_y_chan
10400   END IF
10410   !
10420   GOSUB Condition_input
10430   Ymax=-20000
10440   Ymin=20000
10450   Xmax=-20000
10460   Xmin=20000
10470   Satisfy_sum=0
10480   MAT Satisfy_list= (0)
10490   FOR I=1 TO 343
10500     IF Stats_array(Y_plot_type,Y_channel,I)<>-1.E+6 AND Stats_array(X_plot
_type,X_channel,I)<>-1.E+6 THEN
10510       GOSUB Condition_test
10520       IF Satisfy THEN
10530         Satisfy_sum=Satisfy_sum+1
10540         Satisfy_list(I)=1
10550         Ymax=MAX(Ymax,Stats_array(Y_plot_type,Y_channel,I))
10560         Ymin=MIN(Ymin,Stats_array(Y_plot_type,Y_channel,I))
10570         Xmax=MAX(Xmax,Stats_array(X_plot_type,X_channel,I))
10580         Xmin=MIN(Xmin,Stats_array(X_plot_type,X_channel,I))
10590       END IF
10600     END IF
10610   NEXT I
10620   Data_y_max=Ymax
10630   Data_y_min=Ymin
10640   Data_x_max=Xmax
10650   Data_x_min=Xmin
10660 Re_x_y_plot: !
10670   A=0
10680   B=0
10690   GRAPHICS OFF
10700   PRINT CHR$(12)
10710   PRINT USING "K";"X CHANNEL DATA IS : ";Max_min$(X_channel,X_plot_type);"
OF ";Channel_desc$(X_channel);Units$(X_channel)
10720   PRINT "DATA X MINIMUM = ";Data_x_min;"   PLOT X MINIMUM IS: ";Xmin
10730   PRINT "DATA X MAXIMUM = ";Data_x_max;"   PLOT X MAXIMUM IS: ";Xmax
10740   PRINT USING "K";"Y CHANNEL DATA IS : ";Max_min$(Y_channel,Y_plot_type);"
OF ";Channel_desc$(Y_channel);Units$(Y_channel)
10750   PRINT "DATA Y MINIMUM = ";Data_y_min;"   PLOT Y MINIMUM IS: ";Ymin
10760   PRINT "DATA Y MAXIMUM = ";Data_y_max;"   PLOT Y MAXIMUM IS: ";Ymax
10770   PRINT
10780   PRINT "TOTAL NUMBER OF DATA POINTS INCLUDED IS:";Satisfy_sum
10790   INPUT "ENTER PLOTTING VALUES FOR: Xmin,Xmax",Xmin,Xmax
10800   INPUT "ENTER PLOTTING VALUES FOR: Ymin,Ymax",Ymin,Ymax
10810   IF Ymax<Ymin THEN
10820     Temp=Ymax
10830     Ymax=Ymin
10840     Ymin=Temp
10850   END IF
10860   IF Xmax<Xmin THEN
10870     Temp=Xmax
10880     Xmax=Xmin
10890     Xmin=Temp
10900   END IF
10910   Yscale=Ymax-Ymin
10920   Xscale=Xmax-Xmin
10930   GOSUB X_grad
10940   GOSUB Y_grad
10950   GINIT
```

```
10960  GRAPHICS ON
10970  GCLEAR
10980  PRINT CHR$(12)
10990  VIEWPORT 15,130,13,90
11000  GRAPHICS ON
11010  FRAME
11020  WINDOW Xmin,Xmax,Ymin,Ymax
11030  !
11040  AXES X_tick,Y_tick,Xmin,Ymin,X_major,Y_major,3
11050  LINE TYPE 3
11060  ENABLE
11070 !
11080  MOVE Xmin,0                               ! DRAWS LINES AT  0,0
11090  DRAW Xmax,0
11100  MOVE 0,Ymin
11110  DRAW 0,Ymax
11120 !
11130  LINE TYPE 1
11140  CSIZE 3.0                                  ! NUMBERS X-AXIS
11150  LORG 8
11160  CLIP OFF
11170  Label_increment=X_tick*X_major*2
11180  IF Xscale<=1000 THEN Label_increment=X_tick*X_major
11190  FOR New_counter=Xmin TO Xmax STEP Label_increment
11200     IF ABS(New_counter)<.00001 THEN New_counter=0
11210     New_counter$[1,5]=VAL$(New_counter)
11220     IF POS(New_counter$,".")=0 THEN
11230        Start_pos=6-LEN(VAL$(INT(New_counter)))
11240     ELSE
11250        IF POS(New_counter$,".")=LEN(VAL$(New_counter))-1 THEN
11260           Start_pos=5-POS(New_counter$,".")
11270        ELSE
11280           Start_pos=4-POS(New_counter$,".")
11290        END IF
11300     END IF
11310     Start_pos=MAX(1,Start_pos)
11320     New_counter$[1,5]="     "
11330     New_counter$[Start_pos,5]=VAL$(New_counter)
11340     MOVE New_counter,Ymin-.03*Yscale
11350     LABEL New_counter$
11360  NEXT New_counter
11370  !
11380  Label_increment=Y_tick*Y_major*2                ! NUMBERS Y AXIS
11390  IF Yscale<=1000 THEN Label_increment=Y_tick*Y_major
11400  FOR New_counter=Ymin TO Ymax STEP Label_increment
11410     IF ABS(New_counter)<.0001 THEN New_counter=0
11420     New_counter$[1,5]=VAL$(New_counter)
11430     IF POS(New_counter$,".")=0 THEN
11440        Start_pos=6-LEN(VAL$(INT(New_counter)))
11450     ELSE
11460        IF POS(New_counter$,".")=LEN(VAL$(New_counter))-1 THEN
11470           Start_pos=5-POS(New_counter$,".")
11480        ELSE
11490           Start_pos=4-POS(New_counter$,".")
11500        END IF
11510     END IF
11520     Start_pos=MAX(1,Start_pos)
11530     New_counter$[1,5]="     "
11540     New_counter$[Start_pos,5]=VAL$(New_counter)
11550     MOVE Xmin-.005*Xscale,New_counter
11560     LABEL New_counter$
11570  NEXT New_counter
11580 !
11590  CSIZE 3.5
11600  LORG 5
11610  LDIR 0
```

```
11620  MOVE Xmin+Xscale/2,Ymax+.05*Yscale
11630  LABEL "ROBERT LEMEUR TEST PERIOD DATA - 1984"
11640  LDIR 90
11650  MOVE Xmin-.1*Xscale,Ymin+Yscale/2
11660  LABEL USING "K";Max_min$(Y_channel,Y_plot_type)&" OF "&Channel_desc$(Y_ch
annel)&Units$(Y_channel)
11670  LDIR 0
11680  MOVE Xmin+Xscale/2,Ymin-.10*Yscale
11690  LABEL USING "K";Max_min$(X_channel,X_plot_type)&" OF "&Channel_desc$(X_ch
annel)&Units$(X_channel)
11700  First_point=1
11710  Points_outside=0
11720  CSIZE 2.5
11730  FOR I=1 TO 343
11740     Y_point=Stats_array(Y_plot_type,Y_channel,I)
11750     X_point=Stats_array(X_plot_type,X_channel,I)
11760     IF X_point=-1.E+6 OR Y_point=-1.E+6 OR Satisfy_list(I)=0 THEN Next_poi
nt
11770     IF X_point<Xmin OR X_point>Xmax OR Y_point<Ymin OR Y_point>Ymax THEN
11780        Points_outside=Points_outside+1
11790     ELSE
11800        MOVE X_point,Y_point
11810        LABEL "+"
11820        IF First_point THEN
11830           MOVE X_point,Y_point
11840           CSIZE 5
11850           PEN 0
11860           LABEL "O"
11870           CSIZE 3.3
11880           PEN 1
11890           Current_record=I
11900           First_point=0
11910        END IF
11920     END IF
11930 Next_point:         !
11940  NEXT I
11950  ON KNOB .1,9 GOSUB Move_cursor
11960  RETURN
11970  !
11980 ! ********************************************************************
11990 ! X_GRAD DETERMINES SCALE LABLES FOR X AXIS
12000 ! ********************************************************************
12010 X_grad:!
12020  IF Xscale<=.5 THEN
12030     X_tick=.01
12040  ELSE
12050     IF Xscale<=1 THEN
12060        X_tick=.02
12070     ELSE
12080        IF Xscale<=5 THEN
12090           X_tick=.1
12100        ELSE
12110           IF Xscale<=10 THEN
12120              X_tick=.2
12130           ELSE
12140              IF Xscale<=50 THEN
12150                 X_tick=1
12160              ELSE
12170                 IF Xscale<=100 THEN
12180                    X_tick=2
12190                 ELSE
12200                    IF Xscale<=500 THEN
12210                       X_tick=10
12220                    ELSE
12230                       IF Xscale<=1000 THEN
12240                          X_tick=20
```

```
12250                       ELSE
12260                          X_tick=100
12270                       END IF
12280                    END IF
12290                 END IF
12300              END IF
12310           END IF
12320        END IF
12330     END IF
12340  END IF
12350  X_major=5
12360  RETURN
12370  !
12380 ! ***********************************************************************
12390 ! Y_GRAD DETERMINES SCALE LABLES FOR Y AXIS
12400 ! ***********************************************************************
12410 Y_grad:!
12420  IF Yscale<=.5 THEN
12430     Y_tick=.01
12440  ELSE
12450     IF Yscale<=1 THEN
12460        Y_tick=.02
12470     ELSE
12480        IF Yscale<=5 THEN
12490           Y_tick=.1
12500        ELSE
12510           IF Yscale<=10 THEN
12520              Y_tick=.2
12530           ELSE
12540              IF Yscale<=50 THEN
12550                 Y_tick=1
12560              ELSE
12570                 IF Yscale<=100 THEN
12580                    Y_tick=2
12590                 ELSE
12600                    IF Yscale<=500 THEN
12610                       Y_tick=10
12620                    ELSE
12630                       IF Yscale<=1000 THEN
12640                          Y_tick=20
12650                       ELSE
12660                          Y_tick=100
12670                       END IF
12680                    END IF
12690                 END IF
12700              END IF
12710           END IF
12720        END IF
12730     END IF
12740  END IF
12750  Y_major=5
12760  RETURN
12770  !
12780 ! ==========================================================
12790 ! HELP CURSOR
12800 ! ==========================================================
12810 Help_cursor:!
12820  PRINT CHR$(12)
12830  PRINT "THE CURSOR CAN BE MOVED ALONG THE DATA POINTS USING THE 'KNOB'."
12840  PRINT "THE VALUE INCREASES FOR CLOCKWISE ROTATION AND DEREASES FOR"
12850  PRINT "COUNTER-CLOCKWISE ROTATION. THE POINT IS DESIGNATED BY A 'O'."
12860  PRINT "THE CURRENT TEST NUMBER ,X-VALUE , AND Y-VALUE OF THE POINT ARE"
12870  PRINT "DISPLAYED AT THE BOTTOM OF THE CRT."
12880  PRINT "THE CURSOR WILL ONLY GOTO POINTS ACTUALLY PLOTTED ON THE GRAPHS"
12890  PRINT "THE CURSOR WILL AUTOMATIALLY WRAP ARROUND TO THE OTHER END OF THE"
12900  PRINT "DATA WHEN IT EXCEEDS A LIMIT."
```

```
12910  !
12920 ! ==============================================================
12930 !    MOVE CURSOR
12940 ! ==============================================================
12950 Move_cursor:    !
12960  IF SUM(Satisfy_list)=0 THEN RETURN
12970  CSIZE 5
12980  Knob_value=INT(KNOBX/2)
12990  PEN 0
13000  MOVE Stats_array(X_plot_type,X_channel,Current_record),Stats_array(Y_plot
_type,Y_channel,Current_record)
13010  LABEL "O"
13020  Current_record=(Current_record+Knob_value)
13030 Record_correct: !
13040  IF Current_record>343 THEN Current_record=1
13050  IF Current_record<1 THEN Current_record=343
13060  IF NOT Satisfy_list(Current_record) THEN
13070     Current_record=Current_record+1*SGN(Knob_value)
13080     GOTO Record_correct
13090  END IF
13100  X_variable=Stats_array(X_plot_type,X_channel,Current_record)
13110  Y_variable=Stats_array(Y_plot_type,Y_channel,Current_record)
13120  IF X_variable<Xmin OR X_variable>Xmax OR Y_variable<Ymin OR Y_variable>Ym
ax THEN
13130     Current_record=Current_record+1*SGN(Knob_value)
13140     GOTO Record_correct
13150  END IF
13160  MOVE X_variable,Y_variable
13170  LABEL "O"
13180  PEN 1
13190  CSIZE 3.3
13200  X_var$[1,6]=VAL$(X_variable)
13210  Y_var$[1,6]=VAL$(Y_variable)
13220  DISP CHR$(129)&"DISC RECORD "&VAL$(Current_record)&"; "&X_var$&", "&Y_var
$&CHR$(128)
13230  RETURN
13240 !
13250 ! ==============================================================
13260 ! CONDITIONAL INPUT DATA FROM KEYBOARD
13270 ! ==============================================================
13280 Condition_input:  !
13290  Conditional=1
13300  Bool=1
13310  Conditional$="A"
13320  INPUT "INPUT: USE  ALL DATA or CONDITIONAL ?: A or C  (DEFAULT IS A)",Con
ditional$
13330  Conditional$=UPC$(Conditional$[1,1])
13340  IF (Conditional$)<>"A" AND (Conditional$)<>"C" THEN
13350     BEEP
13360     DISP "RE-";
13370     GOTO Condition_input
13380  END IF
13390  IF Conditional$="A" THEN
13400     Conditional=0
13410     RETURN
13420  END IF
13430     !
13440  PRINT CHR$(12)
13450  PRINT
13460  PRINT "INFORMATION ON CONDITINAL TESTS"
13470  PRINT
13480  PRINT "RELATIONAL OPERATORS:-"
13490  PRINT "                         CHANNEL > VALUE"
13500  PRINT "                         CHANNEL < VALUE"
13510  PRINT "                         CHANNEL = VALUE"
13520  PRINT "                         CHANNEL > CHANNEL"
```

```
13530  PRINT "                              CHANNEL < CHANNEL"
13540  PRINT "                              CHANNEL = CHANNEL"
13550  PRINT
13560  PRINT "FOR MULTIPLE RELATIONAL TESTS :-"
13570  PRINT "                                         BOOLEAN AND"
13580  PRINT "                                         BOOLEAN OR"
13590  PRINT
13600  PRINT " FOR EXAMPLE:-"
13610  PRINT "                    CHANNEL 1 ,COL 1 > 37 AND CHANNEL 5 ,COL 3 < CHANNEL
 7, COL 3"
13620  PRINT " YOU ARE ALLOWED A MAXIMUM OF 10 MULTIPLE RELATIONAL TESTS"
13630  PRINT
13640  FOR K=1 TO 10
13650 Re_input_symbol:INPUT "ENTER: SYMBOL FOR VALUE-COMPARISON or CHANNEL-COMPA
RISON: V or C",Inpt$
13660       Inpt$=UPC$(Inpt$[1,1])
13670       IF Inpt$<>"V" AND Inpt$<>"C" THEN
13680          BEEP
13690          DISP "RE-";
13700          GOTO Re_input_symbol
13710       END IF
13720       IF Inpt$="V" THEN
13730 Comp_input:      !
13740          INPUT "ENTER: CHANNEL# ,COL# , > or < or =, COMPARISON-VALUE",Cond_
channel(K),Cond_type(K),Relational$,Comp_value(K)
13750          IF Cond_channel(K)=34 THEN Cond_channel(K)=22
13760          IF Cond_channel(K)<1 OR Cond_channel(K)>30 OR Cond_type(K)<1 OR Con
d_type(K)>5 THEN
13770             BEEP
13780             DISP "RE-";
13790             GOTO Comp_input
13800          END IF
13810          Relational$=Relational$[1,1]
13820          IF Relational$=">" THEN
13830             Relational(K)=1
13840          ELSE
13850             IF Relational$="<" THEN
13860                Relational(K)=2
13870             ELSE
13880                IF Relational$="=" THEN
13890                   Relational(K)=3
13900                ELSE
13910                   BEEP
13920                   DISP "RE-";
13930                   GOTO Comp_input
13940                END IF
13950             END IF
13960          END IF
13970          IF K<>1 AND Bool=1 THEN PRINT "AND"
13980          IF K<>1 AND Bool=2 THEN PRINT "OR"
13990          PRINT "TEST NUMBER    : ",K
14000          PRINT "TEST CONDITION : ";
14010          PRINT USING "K";Max_min$(Cond_channel(K),Cond_type(K))&" OF "&Chann
el_desc$(Cond_channel(K))&Relational$,Comp_value(K)
14020       ELSE
14030 Comp_ch_input:     !
14040          INPUT "ENTER: CHANNEL#, COL#, > or < or =, CHAN#, COL#",Cond_channe
l(K),Cond_type(K),Relational$,Cond_channel_2(K),Cond_type_2(K)
14050          IF Cond_channel_2(K)=34 THEN Cond_channel_2(K)=22
14060          IF Cond_channel_2(K)<1 OR Cond_channel_2(K)>30 OR Cond_type_2(K)<1
OR Cond_type_2(K)>5 THEN
14070             BEEP
14080             GOTO Comp_ch_input
14090          END IF
14100          !
14110          IF Cond_channel(K)=34 THEN Cond_channel(K)=22
```

```
14120        IF Cond_channel(K)<1 OR Cond_channel(K)>30 OR Cond_type(K)<1 OR Con
d_type(K)>5 THEN
14130           BEEP
14140           DISP "RE-";
14150           GOTO Comp_ch_input
14160        END IF
14170        !
14180        Relational$=Relational$[1,1]
14190        IF Relational$=">" THEN
14200           Relational(K)=4
14210        ELSE
14220           IF Relational$="<" THEN
14230              Relational(K)=5
14240           ELSE
14250              IF Relational$="=" THEN
14260                 Relational(K)=6
14270              ELSE
14280                 BEEP
14290                 DISP "RE-";
14300                 GOTO Comp_ch_input
14310              END IF
14320           END IF
14330        END IF
14340        IF K<>1 AND Bool=1 THEN PRINT "AND"
14350        IF K<>1 AND Bool=2 THEN PRINT "OR"
14360        PRINT "TEST NUMBER     : ",K
14370        PRINT "TEST CONDITION : ";
14380        PRINT USING "K,#";Max_min$(Cond_channel(K),Cond_type(K))&" OF "&Cha
nnel_desc$(Cond_channel(K))&Relational$
14390        PRINT USING "K";Max_min$(Cond_channel_2(K),Cond_type_2(K))&" OF "&C
hannel_desc$(Cond_channel_2(K))
14400     END IF
14410     Bool$="E"
14420     IF K=1 THEN
14430        INPUT "ENTER : AND or OR or EXIT ",Bool$
14440        Bool$=UPC$(Bool$[1,1])
14450        IF Bool$="E" THEN
14460           Number_of_comps=K
14470           RETURN
14480        ELSE
14490           IF Bool$="A" THEN Bool=1
14500           IF Bool$="O" THEN Bool=2
14510        END IF
14520     ELSE
14530 Re_enter_more:INPUT "ENTER : MORE  or EXIT",Bool$
14540        Bool$=UPC$(Bool$[1,1])
14550        IF Bool$="E" THEN
14560           Number_of_comps=K
14570           RETURN
14580        END IF
14590        IF UPC$(Bool$[1,1])<>"M" THEN
14600           BEEP
14610           DISP "RE-";
14620           GOTO Re_enter_more
14630        END IF
14640     END IF
14650  NEXT K
14660  DISP "YOU ,HAVE RUN OUT OF COMPARISON SPACE !!!!!"
14670  RETURN
14680  !
14690 ! ==============================================================
14700 !CONDITIONAL TEST SUBROUTINE
14710 ! ==============================================================
14720 Condition_test:!
14730  Satisfy=1
14740  IF NOT Conditional THEN RETURN
```

```
14750  Satisfy=0
14760  MAT Test_result= (0)
14770  FOR K=1 TO Number_of_comps
14780      ON Relational(K) GOTO Number_1,Number_2,Number_3,Number_4,Number_5,Num
ber_6
14790 Number_1:!
14800      IF Stats_array(Cond_type(K),Cond_channel(K),I)>Comp_value(K) AND Stats
_array(Cond_type(K),Cond_channel(K),I)<>-1.E+6 THEN Test_result(K)=1
14810      GOTO Next_k
14820 Number_2:!
14830      IF Stats_array(Cond_type(K),Cond_channel(K),I)<Comp_value(K) AND Stats
_array(Cond_type(K),Cond_channel(K),I)<>-1.E+6 THEN Test_result(K)=1
14840      GOTO Next_k
14850 Number_3:!
14860      IF Stats_array(Cond_type(K),Cond_channel(K),I)=Comp_value(K) AND Stats
_array(Cond_type(K),Cond_channel(K),I)<>-1.E+6 THEN Test_result(K)=1
14870      GOTO Next_k
14880 Number_4:!
14890      IF Stats_array(Cond_type(K),Cond_channel(K),I)>Stats_array(Cond_type_2
(K),Cond_channel_2(K),I) THEN Test_result(K)=1
14900      IF Stats_array(Cond_type(K),Cond_channel(K),I)=-1.E+6 THEN Test_result
(K)=0
14910      IF Stats_array(Cond_type_2(K),Cond_channel_2(K),I)=-1.E+6 THEN Test_re
sult(K)=0
14920      GOTO Next_k
14930 Number_5: !
14940      IF Stats_array(Cond_type(K),Cond_channel(K),I)<Stats_array(Cond_type_2
(K),Cond_channel_2(K),I) THEN Test_result(K)=1
14950      IF Stats_array(Cond_type(K),Cond_channel(K),I)=-1.E+6 THEN Test_result
(K)=0
14960      IF Stats_array(Cond_type_2(K),Cond_channel_2(K),I)=-1.E+6 THEN Test_re
sult(K)=0
14970      GOTO Next_k
14980 Number_6: !
14990      IF Stats_array(Cond_type(K),Cond_channel(K),I)=Stats_array(Cond_type_2
(K),Cond_channel_2(K),I) THEN Test_result(K)=1
15000      IF Stats_array(Cond_type(K),Cond_channel(K),I)=-1.E+6 THEN Test_result
(K)=0
15010      IF Stats_array(Cond_type_2(K),Cond_channel_2(K),I)=-1.E+6 THEN Test_re
sult(K)=0
15020 Next_k:NEXT K
15030    !
15040  IF Bool=1 THEN    !CHECK FOR "AND"
15050     IF SUM(Test_result)=Number_of_comps THEN Satisfy=1
15060  ELSE              !CHECK FOR "OR"
15070     IF SUM(Test_result)>0 THEN Satisfy=1
15080  END IF
15090  RETURN
15100 ! ==========================================================
15110 ! HELP
15120 ! ==========================================================
15130 Help:!
15140  PRINTER IS 1
15150  OFF KEY
15160  GRAPHICS OFF
15170  !
15180  DISP "PICK A HELP KEY .... ANY KEY ..... EVERYONE IS A WINNER"
15190  !
15200  ON KEY 0 LABEL "X-Y PLOT/RE-PL",2 GOSUB Help_x_y_plot
15210  ON KEY 10 GOSUB Help_re_x_y_pl
15220  ON KEY 1 LABEL "HISTOGRAM/RE-H",2 GOSUB Help_histogram
15230  ON KEY 11 GOSUB Help_re_hist
15240  ON KEY 2 LABEL "LINEAR FIT",2 GOSUB Help_least_fit
15250  ON KEY 12 GOSUB Idle
15260  ON KEY 3 LABEL "DUMP",2 GOSUB Help_dump_graph
15270  ON KEY 13 GOSUB Idle
```

```
15280  ON KEY 4 LABEL "INSTRUCTIONS",2 GOSUB Instructions
15290  ON KEY 14 GOSUB Idle
15300  ON KEY 5 LABEL "CHANNEL DESC.",2 GOSUB Help_channel_de
15310  ON KEY 15 GOSUB Idle
15320  ON KEY 6 LABEL "LIST DATA ",2 GOSUB Help_list_data
15330  ON KEY 16 GOSUB Idle
15340  ON KEY 7 LABEL "ACCEPT LIST ",2 GOSUB Help_accept_lis
15350  ON KEY 17 GOSUB Idle
15360  ON KEY 8 LABEL "CURSOR KNOB" GOSUB Help_cursor
15370  ON KEY 18 GOSUB Idle
15380  ON KEY 9 LABEL "EXIT ",2 GOTO Get_out_of_here
15390  ON KEY 19 GOSUB Idle
15400 Go_nowhere:GOTO Go_nowhere
15410 Get_out_of_here: !
15420  PRINT CHR$(12)
15430  GRAPHICS ON
15440  OFF KEY
15450  DISP ""
15460  IF NOT Running THEN
15470     GOTO Beginning
15480  ELSE
15490     GOTO Above_main_keys
15500  END IF
15510  !
15520!-------------------------------------------------------------
15530! MAIN KEYS
15540!-------------------------------------------------------------
15550 Main_keys:!
15560  ON KEY 0 LABEL "X-Y PLOT RE-PL" GOSUB X_y_plot
15570  ON KEY 10 GOSUB Re_x_y_plot
15580  ON KEY 1 LABEL "HISTOGRAM/RE-H" GOSUB Histogram
15590  ON KEY 11 GOSUB Re_histogram
15600  ON KEY 2 LABEL "LINEAR FIT" GOSUB Least_fit
15610  ON KEY 12 GOSUB Idle
15620  ON KEY 3 LABEL "DUMP" GOSUB Dump_graphics
15630  ON KEY 13 GOSUB Idle
15640  ON KEY 4 LABEL "STOP PROG" GOSUB Top_exit
15650  ON KEY 14 GOSUB Idle
15660  ON KEY 5 LABEL "CHAN/COL DESC." GOSUB Channel_descrip
15670  ON KEY 15 GOSUB Column_descrip
15680  ON KEY 6 LABEL "LIST DATA " GOSUB List_data
15690  ON KEY 16 GOSUB Idle
15700  ON KEY 7 LABEL "ACCEPT LIST " GOSUB Accept_list
15710  ON KEY 17 GOSUB Idle
15720  ON KEY 8 LABEL " " GOSUB Idle
15730  ON KEY 18 GOSUB Idle
15740  ON KEY 9 LABEL "HELP" GOTO Help
15750  ON KEY 19 GOSUB Idle
15760  RETURN
15770 ! ====================================================
15780 !   THE END
15790 ! ====================================================
15800  END
```

```
10     !    PROGRAM: STATDISC4
20     !
30     !    READ IN THE 6 STATISTICS DISC'S WHICH CONTAIN
40     !    THE 343 DATA FILES MINS, MAXS, AND MEANS.
50     !    WRITE OUT THE DATA AS ONE FILE ONTO A SEPARATE
60     !    DISC FOR LATER ANALYSIS VIA THE STATSALYZE PROGRAM.
70     !
80     !    MODIFIED BY : KEN KIRBY
90     !    DATE        : 84:08:28
100    !    VERSION     : STATDISC2
110    !    REASON      : TO FIX "CORRECTIONS" , TO DIVIDE RPM BY 10
120    !                  TO PUT IN REMAINING DESCRIPTIONS AND UNITS
130    !                  TO SET MATRIX TO -1.E+6
140    !                  TO DELETE KNOWN BAD CHANNELS
150    !                  TO ALLOW DISPLAY OF SCIENTIFIC NOTATION
160    !                  TO GET RID OF BAD SLIDING BLOCK SIGNALS
170    !
180    !    MODIFIED BY : KEN KIRBY
190    !    DATE        : 85-01-15
200    !    VERSION     : STATDISC3
210    !    REASON      : TO ALLOW CORRECTIONS OF DATA STORED ON DISK D7
220    !                  WITHOUT RE-READING INTERMEDIATE DISK
230    !                  TO ALLOW LISTING OF CHANNEL DESCRIPTIONS
240    !                  AND TO ALLOW LISTING OF DATA FOR ANY TEST
250    !                  TO PUT IN STATEMENT THAT THE SHAFT TORQUE STORED
260    !                  ON THE STATDISC IS INCORRECT
270    !
280    !    MODIFIED BY : KEN KIRBY
290    !    DATE        : 85-02-11
300    !    VERSION     : STATDISC4
310    !    REASON      : TO COPY NEW STATDISCS WITH THE INFORMATION FOR
320    !                  THE PEAK RADIAL AND CIRC. LOCATION OF THE BLADE
330    !                  FORCE.
340    !                  ALSO COPPIES INFORMATION ON TORQUE AND THRUST
350    !                  EVENTS.
360    !                  SINCE THE DATA IN THE NEW FORMAT ( BOX 'K' )
370    !                  HAS THE GAINS AND OFFSETS FOR THE CHANNELS
380    !                  CORRECTED, REVISED DATA CHECKS.
390    !                  THE STATDISC PRODUCED BY THIS PROGRAM IS DISK 'K7'.
400    !                  THE DATA FROM THIS DISK CAN ONLY BE READ PROPERLY
410    !                  BY VERSIONS OF 'STATALIZE' NUMBERS 7 AND ABOVE.
420    !
430    !   MODIFIED BY :
440    !   DATE        :
450    !   REASON      :
460    !
470     OPTION BASE 1
480    !
490     INTEGER New_disc
500     INTEGER Record_number,I,J,K,L,M,N,L_n
510     REAL Stats_array(1:3,1:30,1:343)
520     REAL Min_value(1:34)
530     REAL Max_value(1:34)
540     REAL Mean_value(1:34)
550     DIM Title$[80]
560     DIM Dates$[12]
570     DIM Times$[12]
580     DIM Channel_desc$(1:30)[27]
590     DIM Channel_sense$(1:30)[35]
600     DIM Units$(1:30)[6]
610     INTEGER N_channels
620     REAL Nscans,Scan_rate,Int_data,Int_pointer,Peak_rad_loc,Peak_circ_loc,Loa
d_dir
630    !
640 Start:  !
650     Array_read=0
```

```
660    !
670     Channel_desc$(1)="BLADE CENTRE BENDING"
680     Channel_desc$(2)="BLADE TRAILING EDGE TORQUE"
690     Channel_desc$(3)="BLADE LEADING EDGE BENDING"
700     Channel_desc$(4)="BLADE CENTRE TORQUE"
710     Channel_desc$(5)="BLADE TRAILING EDGE BENDING"
720     Channel_desc$(6)="BLADE LEADING EDGE TORQUE"
730     Channel_desc$(7)="SLIDING BLOCK FORCE"
740     Channel_desc$(8)="SHAFT THRUST"
750     Channel_desc$(9)="SHAFT TORQUE"
760     Channel_desc$(10)="SERVO OIL PRESSURE"
770     Channel_desc$(11)="LOC. and DIR. OF MAX FORCE"
780     Channel_desc$(12)="AFT TOP PROBE"
790     Channel_desc$(13)="FUEL RACK"
800     Channel_desc$(14)="TYPE OF INTERACTION"
810     Channel_desc$(15)="INTER.#, ICE or WATER, DIR."
820     Channel_desc$(16)="PROPELLER PITCH"
830     Channel_desc$(17)="SHIP SPEED"
840     Channel_desc$(18)="RUDDER ANGLE"
850     Channel_desc$(19)="BLADE BENDING MOMENT"
860     Channel_desc$(20)="BLADE SPINDLE TORQUE"
870     Channel_desc$(21)="BLADE FORCE"
880     Channel_desc$(22)="SHAFT SPEED"
890     Channel_desc$(23)="BLADE START PEAK & DURATION"
900     Channel_desc$(24)="ENERGY kJ;TIME s;FORCE kNs"
910     Channel_desc$(25)="THRUST ST. PK. & END TIME"
920     Channel_desc$(26)="THRUST ST. PK. & END THRUST"
930     Channel_desc$(27)="THRUST ST. PK. & END TORQUE"
940     Channel_desc$(28)="TORQUE ST. PK. & END TIME"
950     Channel_desc$(29)="TORQUE ST. PK. & END THRUST"
960     Channel_desc$(30)="TORQUE ST. PK. & END TORQUE"
970    !
980     Units$(1)="  MPa"
990     Units$(2)="  MPa"
1000    Units$(3)="  MPa"
1010    Units$(4)="  MPa"
1020    Units$(5)="  MPa"
1030    Units$(6)="  MPa"
1040    Units$(7)="  kN"
1050    Units$(8)="  kN"
1060    Units$(9)="  kN.m"
1070    Units$(10)="  bar"
1080    Units$(11)="  m"
1090    Units$(12)="  mm"
1100    Units$(13)="  mm"
1110    Units$(14)=" "
1120    Units$(15)=" "
1130    Units$(16)="  deg"
1140    Units$(17)="  m/s"
1150    Units$(18)="  deg"
1160    Units$(19)="  kN.m"
1170    Units$(20)="  kN.m"
1180    Units$(21)="  kN"
1190    Units$(22)="  rpm"
1200    Units$(23)="  deg"
1210    Units$(24)=" "
1220    Units$(25)="  s"
1230    Units$(26)="  kN"
1240    Units$(27)="  kN.m"
1250    Units$(28)="  s"
1260    Units$(29)="  kN"
1270    Units$(30)="  kN.m"
1280   !
1290    Channel_sense$(1)="POS SIG FOR TIP BENDING FORWARD"
1300    Channel_sense$(2)="POS SIG FOR TRAIL. EDGE BENDING FWD"
1310    Channel_sense$(3)="POS SIG FOR TIP BENDING FORWARD"
```

```
1320   Channel_sense$(4)="POS SIG FOR TRAIL. EDGE BENDING FWD"
1330   Channel_sense$(5)="POS SIG FOR TIP BENDING FORWARD"
1340   Channel_sense$(6)="POS SIG FOR TRAIL. EDGE BENDING FWD"
1350   Channel_sense$(7)="POS SIG FOR TRAIL. EDGE BENDING FWD"
1360   Channel_sense$(8)="POS SIG IS SHAFT IN TENSION"
1370   Channel_sense$(9)="POS SIG IS ENGINE DRIVING SHAFT"
1380   Channel_sense$(10)="POS CHANGE INCREASES PITCH ANGLE"
1390   Channel_sense$(11)="0=BASE 1.06=TIP ;.691=LE 0=CL CIRC."
1400   Channel_sense$(12)="POS CHANGE ,INCREASING SEPARATION"
1410   Channel_sense$(13)="POS CHANGE ,INCREASING FUEL"
1420   Channel_sense$(14)="0=N/E;1=ISOLATED;2=MILL.;3=BLOCKAGE"
1430   Channel_sense$(15)="#:0=WATER,1=ICE:-1=AST,0=STOP,1=AHD"
1440   Channel_sense$(16)="POS SIGNAL ,AHEAD PITCH"
1450   Channel_sense$(17)="ABSOLUTE VALUE OF VELOCITY"
1460   Channel_sense$(18)="POS SIG IS STBD."
1470   Channel_sense$(19)="POS SIG FOR TIP BENDING FORWARD"
1480   Channel_sense$(20)="POS SIG FOR TRAIL. EDGE BENDING FWD"
1490   Channel_sense$(21)="POS SIG FOR TIP BENDING FORWARD"
1500   Channel_sense$(22)="ALWAYS POSITIVE"
1510   Channel_sense$(23)="0 DEG. TOP 90 IS INBOARD, SINGLE BL"
1520   Channel_sense$(24)="TQ. EVENT ENEG. & DUR.; FORCE AREA"
1530   Channel_sense$(25)="THRUST EVENT, AUTO. CHOOSEN"
1540   Channel_sense$(26)="THRUST EVENT,AUTO. CHOOSEN"
1550   Channel_sense$(27)="THRUST EVENT, AUTO. CHOOSEN"
1560   Channel_sense$(28)="TORQUE EVENT, AUTO. CHOOSEN"
1570   Channel_sense$(29)="TORQUE EVENT, AUTO. CHOOSEN"
1580   Channel_sense$(30)="TORQUE EVENT, AUTO. CHOOSEN"
1590  !
1600   MAT Stats_array= (-1.E+6)
1610   False_start=0
1620   !
1630   ! ==============================================================
1640   ! MAIN KEYS
1650   ! ==============================================================
1660   OFF KEY
1670 Main_keys:  !
1680   ON KEY 0 LABEL "STORE STATS   ",3 GOSUB Save_to_disc
1690   ON KEY 1 LABEL "              ",3 GOSUB Idle
1700   ON KEY 2 LABEL "MODIFY STATS  ",3 GOSUB Mod_stats
1710   ON KEY 3 LABEL "              ",3 GOSUB Idle
1720   ON KEY 4 LABEL "XFER INT STATS",3 GOTO Read_inter_disk
1730   ON KEY 5 LABEL "LIST STAT.DATA",3 GOSUB List_data
1740   ON KEY 6 LABEL "              ",3 GOSUB Idle
1750   ON KEY 7 LABEL "MODIFY ALL    ",3 GOSUB Modify_all
1760   ON KEY 8 LABEL "              ",3 GOSUB Idle
1770   ON KEY 9 LABEL "CHAN. DESCRIP.",3 GOSUB Channel_descrip
1780 Here:GOTO Here
1790           !
1800   ! ==============================================================
1810   ! IDLE
1820   ! ==============================================================
1830 Idle:!
1840   RETURN
1850       !
1860   ! ==============================================================
1870   ! READ INTERMEDIATE STATS DISK
1880   ! ==============================================================
1890 Read_inter_disk:  !
1900   OFF KEY
1910   INPUT "PLACE DISC WITH ONE MAG TAPES WORTH OF MIN'S AND MAX'S INTO THE RI
GHT DRIVE",R$
1920 Re_enter_num:  !
1930   INPUT "ENTER RECORD NUMBER OF FIRST FILE FROM THIS DISC",Record_number
1940   IF NOT False_start AND NOT Array_read THEN GOSUB Read_array
1950   IF Stats_array(2,1,Record_number)<>-1.E+6 THEN GOSUB Query_user
1960   IF False_start THEN Re_enter_num
```

```
1970   Record_number=Record_number-1
1980   GOSUB Read_next_file
1990   !
2000   GOSUB Channel_fix
2010 Top_loop:     !
2020   GOSUB Print_to_crt
2030   R$=""
2040   INPUT "ANY CORRECTIONS: Y or CONT",R$
2050   IF UPC$(R$[1,1])="Y" THEN
2060      GOSUB Corrections
2070      GOTO Top_loop
2080   END IF
2090   GOSUB Save_to_array
2100   R$=""
2110   INPUT "NEXT FILE: N or CONT",R$
2120   IF UPC$(R$[1,1])="N" THEN GOTO Save_end
2130   GOSUB Read_next_file
2140   GOSUB Channel_fix
2150   GOTO Top_loop
2160   !
2170 Save_end:     !
2180   GOSUB Save_to_disc
2190   GOTO Start
2200   !
2210   ! =============================================================
2220   !    READ ARRAY FROM CREATED DISC. IE. RE-START OPTION.
2230   ! =============================================================
2240 Read_array:     !
2250   Array_read=1
2260   New_disc=0
2270   INPUT "INSTALL STATSDISC INTO THE LEFT HAND DRIVE (CONTINUE)",R$
2280   ON ERROR GOTO New_disc
2290   ASSIGN @Array_file TO "STATSDISC:INTERNAL,4,1"
2300   ENTER @Array_file;Stats_array(*)
2310   ASSIGN @Array_file TO *
2320   OFF ERROR
2330   RETURN
2340   !
2350   ! =============================================================
2360   ! NEW DISC
2370   ! =============================================================
2380 New_disc:     !
2390   New_disc=1
2400   OFF ERROR
2410   RETURN
2420   !
2430   ! =============================================================
2440   ! QUERY USER
2450   ! =============================================================
2460 Query_user:     !
2470   False_start=0
2480   INPUT "ALREADY HAS DATA IN LARGE DATA ARRAY, IS THIS REALLY WHERE YOU WAN
T TO START?",R$
2490   IF UPC$(R$[1,1])="Y" THEN RETURN
2500   False_start=1
2510   RETURN
2520   !
2530   ! =============================================================
2540   !    DELETES KNOWN BAD CHANNELS OR EMPTY CHANNELS
2550   ! =============================================================
2560 Channel_fix:     !
2570   IF Record_number<6 THEN
2580      FOR I=8 TO 18
2590         IF I=11 OR I=14 OR I=15 THEN Skip_these
2600         Min_value(I)=-1.E+6
2610         Max_value(I)=-1.E+6
```

```
2620          Mean_value(I)=-1.E+6
2630 Skip_these:        !
2640        NEXT I
2650    END IF
2660    IF Record_number=7 THEN
2670       Min_value(6)=-1.E+6
2680       Max_value(6)=-1.E+6
2690       Mean_value(6)=-1.E+6
2700    END IF
2710    IF Record_number>5 AND Record_number<8 THEN
2720       Min_value(7)=-1.E+6
2730       Max_value(7)=-1.E+6
2740       Mean_value(7)=-1.E+6
2750       Min_value(12)=-1.E+6
2760       Max_value(12)=-1.E+6
2770       Mean_value(12)=-1.E+6
2780       Min_value(13)=-1.E+6
2790       Max_value(13)=-1.E+6
2800       Mean_value(13)=-1.E+6
2810    END IF
2820    IF Record_number<13 THEN
2830       Min_value(11)=-1.E+6
2840       Max_value(11)=-1.E+6
2850       Min_value(17)=-1.E+6
2860       Max_value(17)=-1.E+6
2870       Mean_value(17)=-1.E+6
2880       Min_value(22)=-1.E+6
2890       Max_value(22)=-1.E+6
2900       Mean_value(22)=-1.E+6
2910    END IF
2920    IF Record_number>7 AND Record_number<13 THEN
2930       Min_value(7)=-1.E+6
2940       Max_value(7)=-1.E+6
2950       Mean_value(7)=-1.E+6
2960       Min_value(13)=-1.E+6
2970       Max_value(13)=-1.E+6
2980       Mean_value(13)=-1.E+6
2990       Min_value(17)=-1.E+6
3000       Max_value(17)=-1.E+6
3010       Mean_value(17)=-1.E+6
3020    END IF
3030    IF Record_number>12 AND Record_number<15 THEN
3040       Min_value(7)=-1.E+6
3050       Max_value(7)=-1.E+6
3060       Mean_value(7)=-1.E+6
3070    END IF
3080    IF Record_number=13 THEN
3090       Min_value(13)=-1.E+6
3100       Max_value(13)=-1.E+6
3110       Mean_value(13)=-1.E+6
3120    END IF
3130    I=Record_number
3140    IF (I>44 AND I<50) OR (I>51 AND I<55) OR (I>55 AND I<65) OR (I>65 AND I<7
4) OR (I>76 AND I<97) OR (I>110 AND I<121) THEN
3150       Min_value(2)=-1.E+6
3160       Max_value(2)=-1.E+6
3170       Mean_value(2)=-1.E+6
3180    END IF
3190    IF Record_number=114 THEN
3200       Min_value(12)=-1.E+6
3210       Max_value(12)=-1.E+6
3220       Mean_value(12)=-1.E+6
3230    END IF
3240    IF Record_number>58 AND Record_number<117 THEN
3250       Min_value(7)=-1.E+6
3260       Max_value(7)=-1.E+6
```

```
3270        Mean_value(7)=-1.E+6
3280     END IF
3290     IF Record_number>116 AND Min_value(7)<20 THEN
3300        Min_value(7)=-1.E+6
3310        IF Max_value(7)<20 THEN Max_value(7)=-1.E+6
3320        Mean_value(7)=-1.E+6
3330     END IF
3340     IF (Record_number>83 AND Record_number<89) OR Record_number=91 OR Record_
number=93 OR Record_number>206 THEN
3350        Min_value(8)=-1.E+6
3360        Max_value(8)=-1.E+6
3370        Mean_value(8)=-1.E+6
3380        FOR I=25 TO 27
3390           Min_value(I)=-1.E+6
3400           Max_value(I)=-1.E+6
3410           Mean_value(I)=-1.E+6
3420        NEXT I
3430        Min_value(29)=-1.E+6
3440        Max_value(29)=-1.E+6
3450        Mean_value(29)=-1.E+6
3460     END IF
3470     IF Record_number>298 THEN
3480        Min_value(4)=-1.E+6
3490        Max_value(4)=-1.E+6
3500        Mean_value(4)=-1.E+6
3510     END IF
3520     IF Min_value(17)<.1 THEN Min_value(17)=-1.E+6
3530     IF Max_value(17)<.1 THEN Max_value(17)=-1.E+6
3540     IF Mean_value(17)<.1 THEN Mean_value(17)=-1.E+6
3550     RETURN
3560   !
3570   ! ============================================================
3580   !    SAVE ARRAY TO DISC
3590   ! ============================================================
3600 Save_to_disc:     !
3610     IF New_disc THEN CREATE BDAT "STATSDISC:INTERNAL,4,1",970
3620     ASSIGN @Array_file TO "STATSDISC:INTERNAL,4,1"
3630     OUTPUT @Array_file;Stats_array(*)
3640     ASSIGN @Array_file TO *
3650     RETURN
3660   !
3670   ! ============================================================
3680   !    READ STATS DATA FROM THE 343 FILES, ON THE 6 STATS DISC'S
3690   ! ============================================================
3700 Read_next_file:     !
3710     Record_number=Record_number+1
3720     ON ERROR GOTO Read_error
3730 After_error:ASSIGN @Data_file TO "STATS"&VAL$(Record_number)
3740     ENTER @Data_file;Title$,Dates$,Times$,N_channels,Nscans,Scan_rate,Int_dat
a,Int_pointer,Min_value(*),Max_value(*),Mean_value(*)
3750     ASSIGN @Data_file TO *
3760     OFF ERROR
3770     Min_value(22)=Min_value(34)
3780     Max_value(22)=Max_value(34)
3790     Mean_value(22)=Mean_value(34)
3800     RETURN
3810   !
3820 Read_error:     !
3830     IF Record_number=344 THEN
3840        GOTO Save_end
3850     ELSE
3860        PRINT
3870        PRINT "CAN'T FIND STATS";Record_number;"  YOU TURKEY"
3880        PRINT
3890        BEEP
3900        Cont_read$=""
```

```
3910        INPUT "DO YOU WANT TO CONTINUE : N or CONT ",Cont_read$
3920        IF UPC$(Cont_read$)="N" THEN Save_end
3930        Record_number=Record_number+1
3940     END IF
3950     GOTO After_error
3960    !
3970    ! =======================================================
3980    !    SAVE DATA INTO THE STATS ARRAY
3990    ! =======================================================
4000 Save_to_array:     !
4010     FOR I=1 TO 13
4020        Stats_array(1,I,Record_number)=Min_value(I)
4030        Stats_array(2,I,Record_number)=Max_value(I)
4040        Stats_array(3,I,Record_number)=Mean_value(I)
4050     NEXT I
4060     FOR I=16 TO 22
4070        Stats_array(1,I,Record_number)=Min_value(I)
4080        Stats_array(2,I,Record_number)=Max_value(I)
4090        Stats_array(3,I,Record_number)=Mean_value(I)
4100     NEXT I
4110     Stats_array(3,24,Record_number)=Mean_value(24)
4120     FOR I=25 TO 30
4130        Stats_array(1,I,Record_number)=Min_value(I)
4140        Stats_array(2,I,Record_number)=Max_value(I)
4150        Stats_array(3,I,Record_number)=Mean_value(I)
4160     NEXT I
4170     RETURN
4180    !
4190    ! =======================================================
4200    !    PRINT DATA TABLE TO THE CRT
4210    ! =======================================================
4220 Print_to_crt:     !
4230    PRINT TAB(5);"R. LEMEUR  PROPELLER BLADE TEST 1984";TAB(50);"STATS";VAL$(
Record_number)
4240    PRINT
4250    PRINT " #    CHANNEL  DESCRIPTION";TAB(41);"MIN        MAX        MEAN
UNITS"
4260    PRINT
4270 Min_max_image:IMAGE DD,4X,30A,3(2X,SDDDD.DD),3X,6A
4280 Bad_data_image:IMAGE DD,4X,30A,3(2X,SD.DE),3X,6A
4290    FOR I=1 TO 30
4300       IF Max_value(I)=-1.E+6 OR Min_value(I)=-1.E+6 OR Mean_value(I)=-1.E+6
THEN
4310          PRINT USING Bad_data_image;I,Channel_desc$(I),Min_value(I),Max_valu
e(I),Mean_value(I),Units$(I)
4320       ELSE
4330          PRINT USING Min_max_image;I,Channel_desc$(I),Min_value(I),Max_value
(I),Mean_value(I),Units$(I)
4340       END IF
4350    NEXT I
4360    RETURN
4370   !
4380   ! =======================================================
4390   !    CORRECTIONS TO THE INPUT DATA ARRAY
4400   ! =======================================================
4410 Corrections:     !
4420    INPUT "ENTER CHANNEL # IN ERROR",Channel_no
4430    IF Channel_no=34 THEN Channel_no=22
4440    IF Channel_no<1 OR Channel_no>30 THEN GOTO Top_loop
4450    PRINT "ENTER NOTHING FOR SAME VALUE, AND -1E6 FOR NO VALUE"
4460    INPUT "ENTER NEW MIN VALUE (CONTINUE)",Min_value(Channel_no)
4470    INPUT "ENTER NEW MAX VALUE (CONTINUE)",Max_value(Channel_no)
4480    INPUT "ENTER NEW MEAN VALUE (CONTINUE)",Mean_value(Channel_no)
4490    RETURN
4500   !
4510   ! =======================================================
4520  ! DISPLAY OF CHANNEL DESRIPTIONS
4530  ! ============================================================
4540 Channel_descrip: !
4550    Inpt$=""
4560    INPUT " DO YOU WANT A HARDCOPY ?: Y or CONT",Inpt$
4570    IF UPC$(Inpt$[1,1])="Y" THEN PRINTER IS 701
4580    PRINT
4590    Chan_tab=2
4600    Des_tab=8
4610    Units_tab=35
4620    Sense_tab=45
4630    PRINT "CHAN#";TAB(Des_tab);"CHANNEL DESCRIPTIONS";TAB(Units_tab);"UNITS";
TAB(Sense_tab);"COMMENTS"
4640    PRINT
4650    FOR I=1 TO 30
4660       PRINT TAB(Chan_tab);I;TAB(Des_tab);Channel_desc$(I);TAB(Units_tab);Uni
ts$(I);TAB(Sense_tab);Channel_sense$(I)
4670    NEXT I
4680    IF UPC$(Inpt$[1,1])="Y" THEN PRINT CHR$(12)
4690    PRINTER IS 1
4700    RETURN
4710    !
4720  ! ============================================================
4730  ! DISPLAY OF THE DATA CONTAINED IN A PARTICULAR EVENT
4740  ! ============================================================
4750 List_data: !
4760    IF NOT Array_read THEN GOSUB Read_array
4770    Inpt$=""
4780    INPUT " DO YOU WANT A HARDCOPY? : Y or CONT",Inpt$
4790    IF UPC$(Inpt$[1,1])="Y" THEN PRINTER IS 701
4800 Re_enter_l_n:!
4810    INPUT "ENTER THE EVENT NUMBER YOU WANT DIPLAYED:",L_n
4820    IF L_n<1 OR L_n>343 THEN
4830       DISP "RE-";
4840       BEEP
4850       GOTO Re_enter_l_n
4860    END IF
4870    PRINT
4880    PRINT TAB(5);"DATA FOR EVENT NUMBER : ";L_n
4890    PRINT
4900    PRINT " #          CHANNEL                                     MIN       MAX       MEA
N    UNITS"
4910    PRINT
4920 P_list_2:IMAGE 2D,2A,35A,3(10A),2A,6A
4930    FOR K=1 TO 30
4940       FOR I=1 TO 3
4950          IF Stats_array(I,K,L_n)=-1.E+6 THEN
4960             Temp_print$(I)[1,10]="    N/A   "
4970          ELSE
4980             Temp_print$(I)[1,10]=VAL$(INT((Stats_array(I,K,L_n)*100))/100)
4990             IF POS(Temp_print$(I),".")=0 THEN
5000                Start_pos=7-LEN(VAL$(INT((Stats_array(I,K,L_n)*100))/100))
5010             ELSE
5020                Start_pos=8-POS(Temp_print$(I),".")
5030             END IF
5040             Start_pos=MAX(1,Start_pos)
5050             Temp_print$(I)[1,10]="          "
5060             Temp_print$(I)[Start_pos,10]=VAL$(INT((Stats_array(I,K,L_n)*100)
)/100)
5070          END IF
5080       NEXT I
5090       PRINT USING P_list_2;K," ",Channel_desc$(K),Temp_print$(1),Temp_print$
(2),Temp_print$(3),"  ",Units$(K)
5100    NEXT K
5110 !
5120    PRINT
```

```
5130   PRINT TAB(5);" N/A - MEANS 'NO DATA AVAILABLE'."
5140   IF UPC$(Inpt$[1,1])="Y" THEN PRINT CHR$(12)
5150   PRINTER IS 1
5160   RETURN
5170  !
5180  ! ==========================================================
5190  !   MODIFY STATISTICS
5200  ! ==========================================================
5210 Mod_stats:     !
5220   IF NOT Array_read THEN GOSUB Read_array
5230   Inpt$=""
5240   GOSUB Re_enter_l_n
5250 Some_more:                    !
5260   INPUT "ENTER CHANNEL # IN ERROR",Channel_no
5270   IF Channel_no=34 THEN Channel_no=22
5280   IF Channel_no<1 OR Channel_no>30 THEN
5290      DISP "RE-";
5300      BEEP
5310      GOTO Some_more
5320   END IF
5330   IF Channel_no<23 AND Channel_no<>11 AND Channel_no<>14 AND Channel_no<>15
 THEN
5340      INPUT "ENTER: NEW MIN VALUE or CONT",Stats_array(1,Channel_no,L_n)
5350      INPUT "ENTER: NEW MAX VALUE or CONT",Stats_array(2,Channel_no,L_n)
5360      INPUT "ENTER: NEW MEAN VALUE or CONT",Stats_array(3,Channel_no,L_n)
5370   END IF
5380   IF Channel_no=11 THEN
5390      INPUT "ENTER: RADIAL LOCATION OF PEAK BLADE FORCE: ( m ) or CONT",Stat
s_array(1,Channel_no,L_n)
5400      INPUT "ENTER; CIRC LOCATION OF PEAK BLADE FORCE: ( m ) or CONT",Stats_
array(2,Channel_no,L_n)
5410      INPUT "ENTER; SENSE OF BLADE FORCE POS or NEG : -1 or 1 or CONT",Stats
_array(3,Channel_no,L_n)
5420   END IF
5430   IF Channel_no=14 THEN
5440      INPUT "ENTER FIRST EVENT TYPE; N/E,Isolated,Milling,Blockage:0,1,2,3 o
r CONT",Stats_array(1,Channel_no,L_n)
5450      INPUT "ENTER SECOND EVENT TYPE; N/E,Isolated,Milling,Blockage:0,1,2,3
or CONT",Stats_array(2,Channel_no,L_n)
5460      INPUT "ENTER THIRD EVENT TYPE; N/E,Isolated,Milling,Blockage:0,1,2,3 o
r CONT",Stats_array(3,Channel_no,L_n)
5470   END IF
5480   IF Channel_no=15 THEN
5490      INPUT "ENTER: Interrupt # or CONT",Stats_array(1,Channel_no,L_n)
5500      INPUT "ENTER; Open water or Ice : 0 or 1 or CONT",Stats_array(2,Channe
l_no,L_n)
5510      INPUT "ENTER; Astern or Stopped or Ahead : -1 or 0 or 1 or CONT",Stats
_array(3,Channel_no,L_n)
5520   END IF
5530   IF Channel_no=23 THEN
5540      INPUT "ENTER: ORIENTATION AT START ( Deg ) or CONT",Stats_array(1,Chan
nel_no,L_n)
5550      INPUT "ENTER: ORIENTATION AT PEAK ( Deg ) or CONT",Stats_array(2,Chann
el_no,L_n)
5560      INPUT "ENTER: DURATION OF EVENT ( Deg ) or CONT",Stats_array(3,Channel
_no,L_n)
5570   END IF
5580   IF Channel_no=24 THEN
5590      INPUT "ENTER: INTERACTION ENERGY ( kJ ) or CONT",Stats_array(1,Channel
_no,L_n)
5600      INPUT "ENTER: DURATION TIME ( sec ) or CONT",Stats_array(2,Channel_no,
L_n)
5610      INPUT "ENTER: BLADE FORCE INTERACTION AREA ( kN.sec ) or CONT",Stats_a
rray(3,Channel_no,L_n)
5620   END IF
5630   IF Channel_no=25 THEN
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5640      INPUT "ENTER: THRUST EVENT START TIME ( sec ) or CONT",Stats_array(1,C
hannel_no,L_n)
5650      INPUT "ENTER: THRUST EVENT PEAK TIME ( sec ) or CONT",Stats_array(2,Ch
annel_no,L_n)
5660      INPUT "ENTER: THRUST EVENT END TIME ( sec ) or CONT",Stats_array(3,Cha
nnel_no,L_n)
5670   END IF
5680   IF Channel_no=26 THEN
5690      INPUT "ENTER: THRUST EVENT START THRUST ( kN ) or CONT",Stats_array(1,
Channel_no,L_n)
5700      INPUT "ENTER: THRUST EVENT PEAK THRUST ( kN ) or CONT",Stats_array(2,C
hannel_no,L_n)
5710      INPUT "ENTER: THRUST EVENT END THRUST ( kN ) or CONT",Stats_array(3,Ch
annel_no,L_n)
5720   END IF
5730   IF Channel_no=27 THEN
5740      INPUT "ENTER: THRUST EVENT START TORQUE ( kN.m ) or CONT",Stats_array(
1,Channel_no,L_n)
5750      INPUT "ENTER: THRUST EVENT PEAK TORQUE ( kN.m ) or CONT",Stats_array(2
,Channel_no,L_n)
5760      INPUT "ENTER: THRUST EVENT END TORQUE ( kN.m ) or CONT",Stats_array(3,
Channel_no,L_n)
5770   END IF
5780   IF Channel_no=28 THEN
5790      INPUT "ENTER: TORQUE EVENT START TIME ( sec ) or CONT",Stats_array(1,C
hannel_no,L_n)
5800      INPUT "ENTER: TORQUE EVENT PEAK TIME ( sec ) or CONT",Stats_array(2,Ch
annel_no,L_n)
5810      INPUT "ENTER: TORQUE EVENT END TIME ( sec ) or CONT",Stats_array(3,Cha
nnel_no,L_n)
5820   END IF
5830   IF Channel_no=29 THEN
5840      INPUT "ENTER: TORQUE EVENT START THRUST ( kN ) or CONT",Stats_array(1,
Channel_no,L_n)
5850      INPUT "ENTER: TORQUE EVENT PEAK THRUST ( kN ) or CONT",Stats_array(2,C
hannel_no,L_n)
5860      INPUT "ENTER: TORQUE EVENT END THRUST ( kN ) or CONT",Stats_array(3,Ch
annel_no,L_n)
5870   END IF
5880   IF Channel_no=30 THEN
5890      INPUT "ENTER: TORQUE EVENT START TORQUE ( kN.m ) or CONT",Stats_array(
1,Channel_no,L_n)
5900      INPUT "ENTER: TORQUE EVENT PEAK TORQUE ( kN.m ) or CONT",Stats_array(2
,Channel_no,L_n)
5910      INPUT "ENTER: TORQUE EVENT END TORQUE ( kN.m ) or CONT",Stats_array(3,
Channel_no,L_n)
5920   END IF
5930   Any_more$=""
5940   INPUT "ANY MORE CORRECTIONS ON THIS TEST: N or CONT",Any_more$
5950   IF UPC$(Any_more$[1,1])<>"N" THEN Some_more
5960   RETURN
5970   !
5980   ! ========================================================
5990   !    MODIFY ALL
6000   ! ========================================================
6010 Modify_all:     !
6020   IF NOT Array_read THEN GOSUB Read_array
6030   INPUT "ENTER CHANNEL # IN ERROR",Channel_no
6040   IF Channel_no=34 THEN Channel_no=22
6050   IF Channel_no<1 OR Channel_no>30 THEN
6060      DISP "RE-";
6070      BEEP
6080      GOTO Some_more
6090   END IF
6100 Re_input_col:  !
6110   INPUT "ENTER COLUMN TO CHANGE : MIN , MAX or MEAN",This_col$
```

```
6120   IF UPC$(This_col$[1,3])="MIN" THEN
6130      Column=1
6140   ELSE
6150      IF UPC$(This_col$[1,3])="MAX" THEN
6160         Column=2
6170      ELSE
6180         IF UPC$(This_col$[1,4])="MEAN" THEN
6190            Column=3
6200         ELSE
6210            BEEP
6220            DISP "RE-";
6230            GOTO Re_input_col
6240         END IF
6250      END IF
6260   END IF
6270   Start_event=1
6280   INPUT "AT WHAT EVENT NUMBER DO YOU WANT TO START ?",Start_event
6290   INPUT "AT WHAT EVENT NUMBER DO YOU WANT TO STOP ?",Stop_event
6300   IF Stop_event>343 THEN Stop_event=343
6310   IF Stop_event<Start_event THEN Stop_event=Start_event
6320   PRINT "EVENT     ";"OLD ";This_col$;" VALUE       NEW ";This_col$;" VALUE"
6330   PRINT
6340   FOR L_n=Start_event TO Stop_event
6350      IF ABS(Stats_array(Column,Channel_no,L_n))>999 THEN
6360         PRINT USING "DDDD,6X,SD.DDDE,#";L_n,Stats_array(Column,Channel_no,L
_n)
6370      ELSE
6380         PRINT USING "DDDD,6X,DDD.DDD,#";L_n,Stats_array(Column,Channel_no,L
_n)
6390      END IF
6400      IF Channel_no<23 AND Channel_no<>11 AND Channel_no<>14 AND Channel_no<
>15 THEN
6410         DISP "ENTER: NEW ";This_col$;" VALUE or CONT",Stats_array(Column,Ch
annel_no,L_n)
6420         INPUT Stats_array(Column,Channel_no,L_n)
6430      ELSE
6440         IF Column=1 THEN
6450            INPUT "ENTER: FIRST COLUMN or CONT",Stats_array(1,Channel_no,L_n
)
6460         ELSE
6470            IF Column=2 THEN
6480               INPUT "ENTER: SECOND COLUMN or CONT",Stats_array(2,Channel_no
,L_n)
6490            ELSE
6500               INPUT "ENTER: THIRD COLIMN or CONT",Stats_array(3,Channel_no,
L_n)
6510            END IF
6520         END IF
6530      END IF
6540      IF ABS(Stats_array(Column,Channel_no,L_n))>999 THEN
6550         PRINT USING "10X,SD.DDDE";Stats_array(Column,Channel_no,L_n)
6560      ELSE
6570         PRINT USING "10X,DDD.DDD";Stats_array(Column,Channel_no,L_n)
6580      END IF
6590   NEXT L_n
6600   BEEP
6610   PRINT
6620   DISP CHR$(129);"THAT'S THIS ONE DONE. I SUGGEST YOU STORE IT";CHR$(128)
6630   RETURN
6640 !
6650 ! ============================================================
6660 !   THE END
6670 ! ============================================================
6680 The_end: !
6690   DISP "THAT'S ALL FOR NOW .... BYE..."
6700   END
```

```
10    ! Program HSDAR /M. H. Edgecombe /84-05-17
20    !
30    ! VERSION HSDAR4_3 TO INCLUDE CALCULATION OF LEAST SQUARE FIT OF G1 TO G6
40    ! AND LEAST SQUARED FIT OF SELECTED POINTS
50    ! P.A.S. 84/05/24
60    !
70    ! MODIFIED BY : KEN KIRBY
80    ! DATE        : 84-10-22
90    ! REASON      : TO CALCULATE SLOPE OF SELECTED POINTS
100   !               CHANGE FORMAT OF GRAPH
110   !               GOT RID OF NEGATIVE SIGN ON LOAD CELL VOLTAGE
120   !
130   ! MODIFIED BY : KEN KIRBY
140   ! DATE        : 84-11-09
150   ! REASON      : TO ALLOW DATA TO BE SCALED AS IF IT HAD BEEN RECORDED
160   !               AT THE SAME GAINS AS DURING THE SHIP TESTING PERIOD
170   !               WITH A MESSAGE AS TO THE SCALE USED
180   !
190   ! MODIFIED BY : KEN KIRBY
200   ! DATE        : 85-01-10
210   ! REASON      : TO ALLOW THE CALCULATION OF THE LEAST SQUARE FIT LINE
220   !               THROUGH ANY POINTS CHOSEN
230   !
240   ! MODIFIED BY : KEN KIRBY
250   ! DATE        : 85-01-27
260   ! REASON      : TO ALLOW CROSS LINES OR A '0' TO GO WITH THE MOVE CURSOR
270   !               TO DISPLAY THE TIME AND X-Y VALUE OF POINTS BEING PLOTTED
280   !
290   ! MODIFIED BY :
300   ! DATE        :
310   ! REASON      :
320   !
330   ! High Speed Data Acquisition Routine for the HP 9836 desktop computer
340   ! and the HP 6940B multiprogrammer.
350   !
360   ! Hardware Configuration:
370   !     - 1 of HP Series 200 model 36 desktop computer (HP 9836)
380   !     - 6 of HP 98256 256K RAM memory boards installed in the 9836
390   !     - 1 of HP 98622A opt. 003 GP-IO interface (select code 12)
400   !
410   !     - 1 of HP 6940B multiprogrammer mainframes connected to the HP9836
420   !       via the HP 98622A GP-IO interface and opt. 003 cable.
430   !     - 1 of HP 69351B voltage regulator card installed in m/p slot 600
440   !     - 1 of HP 69602A timer/pacer card installed in m/p slot 400
450   !     - 1 of HP 69422A high speed a/d card installed in m/p slot 401
460   !     - 2 of HP 69336B high speed scanner cards installed in m/p slots 402
470   !       and 403
480   !
490   ! Operating System and Extensions:
500   !     - BASIC 2.0
510   !     - BASIC Extensions 2.1
520   !
530     OPTION BASE 1
540     INTEGER I,J,K,L,M,N,Nchnls,Nrdgs,Nbytes,Range
550     INTEGER Period,Nscans,Form,Lines,Start_line
560     INTEGER V(1,8) BUFFER,A(1,8),Rdgs(500,8)
570     DIM Title$[80],Date$[12],Time$[12],Sig$(2,8)[9],File$[25],Slope(7),Interc
ept(7),Value(7),Message_scale$[80],Comp_tests$(50)[10]
580     REAL Sumx,Sumxsq,Sumy,Sumxy,Xpoint,Ypoint
590    !
600     Scan_period=.1
610     Nchnls=8
620     Nrdgs=1
630     Nwords=Nrdgs*Nchnls
640     Nbytes=Nwords*2
650     Form=18
```

```
660    Phi=9999
670    !
680    DATA "   LE    ","   LE    ","   TE    ","   TE    "
690    DATA " CENTRE  "," CENTRE  "," SLIDING "," APPLIED "
700    DATA " BENDING ","  TORQUE "," BENDING ","  TORQUE "
710    DATA " BENDING ","  TORQUE ","  BLOCK  ","   LOAD  "
720    READ Sig$(*)
730    !
740    DATA "PT1_C2    ","PT1_C3    ","PT2_C1    ","PT2_C1_2  ","PT2_C2    "
750    DATA "PT2_C3    ","PT4_C2    ","PT4_C3    ","PT4_C5    ","PT5_C3    "
760    DATA "PT5_C5    ","PT7_C2    ","PT7_C3    ","PT7_C4    ","PT8_C3    "
770    DATA "PT9_C2    ","PT9_C3    ","PT9_C3_2  ","PT10_C2   ","PT10_C3   "
780    DATA "PT10_C4   ","PT11_C2   ","PT11_C4   ","PT12_C2   ","PT12_C2_2 "
790    DATA "PT12_C3   ","PT15_C2   ","PT15_C3   ","PT17_C2   ","PT17_C3   "
800    DATA "PT19_C3   ","PT20_C3   ","PT21_C2   ","PT22_C2   ","PT22_C3   "
810    DATA "PT24_C2   ","PT24_C3   ","PT24_C4   ","PT24_C5   ","PT25_C2   "
820    DATA "PT25_C3   ","PT29_C2   ","PT29_C3   ","PT30_C2   ","PT31_C2   "
830    DATA "PT32_C2   ","PT32_C3   ","PT33_C3   ","PT34_C2   ","PT35_C2   "
840    READ Comp_tests$(*)
850    !
860    All_tests=50
870    !
880    ASSIGN @Buffer TO BUFFER V(*);WORD
890 !ASSIGN @Multiprogrammer TO 12;WORD
900   !
910    Timer_card=0
920    Ad_card=4096
930    Scanner_card0=8192
940    Scanner_card1=12288
950    Cw=-4096
960    Isl=128
970    Dte=64
980    Sye=32
990    Tme=16
1000   Point_plot=1
1010 Ctl_fmt:IMAGE #,W
1020   !
1030   ! ********************************************************************
1040   ! START
1050   ! ********************************************************************
1060 Start: !
1070   ON ERROR GOTO Driver
1080   IF TIMEDATE<2.09E+11 THEN GOSUB Set_time
1090   Nscans=0
1100   Change_gain=1
1110   GOTO Scale_data
1120   !
1130   ! *****************************************************************
1140   ! DRIVER
1150   ! *****************************************************************
1160 Driver: !
1170   Other_idle=0
1180   OFF KEY
1190   ON KEY 0 LABEL "START SCAN",3 GOTO Scan
1200   ON KEY 5 LABEL "STOP SCAN",3 GOTO Driver
1210   ON KEY 1 LABEL "LIST DATA",3 GOTO List_data
1220   ON KEY 6 LABEL "PLOT DATA",3 GOTO Graphics
1230   ON KEY 2 LABEL "SAVE DATA",3 GOTO Save_data
1240   ON KEY 7 LABEL "GET DATA",3 GOTO Get_data
1250   ON KEY 3 LABEL "SLOPES",3 GOTO Slopes
1260   ON KEY 4 LABEL "SCALE",3 GOTO Scale_data
1270   ON KEY 8 LABEL " ",3 GOTO Idle
1280   ON KEY 9 LABEL " ",3 GOTO Idle
1290 !
1300 Idle:!
1310   IF NOT Other_idle THEN
```

```
1320       GOSUB Display_time
1330       GOTO Idle
1340    ELSE
1350       GOTO G_idle
1360    END IF
1370 !
1380 ! *************************************************************************
1390 ! SCAN
1400 ! *************************************************************************
1410 Scan: !
1420    PRINT CHR$(12)
1430    GOSUB Print_header
1440 !
1450 ! *************************************************************************
1460 ! SAMPLE LOOP
1470 ! *************************************************************************
1480 Sample_loop:!
1490    GOSUB Sample
1500    I=Nscans
1510    GOSUB Print_volts
1520    IF Lines>=Form THEN GOSUB Print_header
1530    WAIT Scan_period
1540    GOTO Sample_loop
1550  !
1560 ! ************************************************************************
1570 ! SAMPLE
1580 ! ************************************************************************
1590 Sample:  !
1600    DISABLE
1610    RESET 12
1620    Range=0          ! timer increment is 10^Range microseconds
1630    Range=2^Range
1640    Period=500       ! time between channels is 2XPeriod*Range
1650    Start_channel=7
1660 !
1670 ! ************************************************************************
1680 ! SAMPLE RATE
1690 ! ************************************************************************
1700 Sample_rate: !
1710    OUTPUT 12 USING Ctl_fmt;Cu+Sye
1720    OUTPUT 12 USING Ctl_fmt;Timer_card+3072+Range
1730    OUTPUT 12 USING Ctl_fmt;Timer_card+Period
1740 !
1750 ! ************************************************************************
1760 ! START CHANNEL
1770 ! ************************************************************************
1780 Start_chan: !
1790    OUTPUT 12 USING Ctl_fmt;Cu+Sye
1800    OUTPUT 12 USING Ctl_fmt;Scanner_card1+2048+16          ! 2048=disabled
1810    OUTPUT 12 USING Ctl_fmt;Scanner_card0+Start_channel    ! enabled
1820 !
1830 ! ***********************************************************************
1840 ! ADDRESS A/D CARD
1850 ! ***********************************************************************
1860 Address_adc: !
1870    OUTPUT 12 USING Ctl_fmt;Cu+Isl+Sye+Tme
1880    CONTROL 12,3;Ad_card
1890 !
1900 ! **********************************************************************
1910 ! TRANSFER DATA
1920 ! **********************************************************************
1930 Transfer: !
1940    T1=TIMEDATE
1950    TRANSFER @Multiprogrammer TO @Buffer;COUNT Nbytes,WAIT
1960 ! Busy:    STATUS @Buffer,10;Stat
1970 !          IF BIT(Stat,6) THEN Busy
```

```
1980   T2=TIMEDATE
1990 !
2000 ! **********************************************************************
2010 ! SHUT DOWN DATA TRANSFER
2020 ! **********************************************************************
2030 Shut_down: !
2040   OUTPUT 12 USING Ctl_fmt;Cw+Sye+Dte
2050   OUTPUT 12 USING Ctl_fmt;Timer_card+Period
2060   OUTPUT 12 USING Ctl_fmt;Timer_card+3072
2070 !
2080 !
2090 ! **********************************************************************
2100 ! CONVERT READINGS TO BIT COUNTS
2110 ! **********************************************************************
2120 Convert: !
2130   MAT V= V+(32768)
2140   MAT A= (2047)
2150   MAT A= V>A
2160   MAT A= A*(-4096)
2170   MAT V= V+A
2180   !
2190   Nscans=Nscans+1
2200   FOR I=1 TO 8
2210      Rdgs(Nscans,I)=V(1,I)
2220   NEXT I
2230   !
2240   CONTROL @Buffer,5;1
2250   CONTROL @Buffer,4;1
2260   CONTROL @Buffer,3;1
2270   IF Nscans>=500 THEN GOTO Driver
2280   !
2290   ENABLE
2300   RETURN
2310 !
2320 ! **********************************************************************
2330 ! GRAPHICS
2340 ! **********************************************************************
2350 Graphics: !
2360   Other_idle=1
2370   GCLEAR
2380   Join$=""
2390   INPUT "ENTER NUMBER OF SIGNAL TO BE PLOTTED...",Sig
2400   Xmin=-7
2410   Ymin=-.40
2420   Xmax=1
2430   Ymax=.40
2440   PRINT CHR$(12)
2450   GOSUB Plot
2460   !
2470   GOSUB Cursor_knob
2480   !
2490   ON KEY 0 LABEL "Inc/ Dec YMAX",3 GOTO Ymaxinc
2500   ON KEY 10,3 GOTO Ymaxdec
2510   ON KEY 1 LABEL "Cursor Knob",3 GOSUB Cursor_knob
2520   ON KEY 5 LABEL "Dec/ Inc YMIN",3 GOTO Ymindec
2530   ON KEY 15,3 GOTO Ymininc
2540   ON KEY 6 LABEL "Lines Knob",3 GOSUB Lines_knob
2550   ON KEY 4 LABEL "New Plot",3 GOTO Graphics
2560   ON KEY 2 LABEL "Least Square",3 GOTO Mod_least_sq
2570   ON KEY 7 LABEL "Lower Limit",3 GOSUB Lower_limit
2580   ON KEY 8 LABEL "Upper Limit",3 GOSUB Upper_limit
2590   ON KEY 9 LABEL "EXIT",3 GOTO Exit
2600   ON KEY 3 LABEL "POINTS/LINE",3 GOTO Points_line
2610   OFF ERROR
2620 G_idle:GOTO G_idle
2630  !
```

```
2640  ! ***********************************************************************
2650  ! CURSOR KNOB
2660  ! ***********************************************************************
2670 Cursor_knob: !
2680   ON KNOB .1,9 GOSUB Move_cursor
2690   RETURN
2700   !
2710  ! ***********************************************************************
2720  ! LINES KNOB
2730  ! ***********************************************************************
2740 Lines_knob: !
2750   ON KNOB .1,9 GOSUB Move_lines
2760   RETURN
2770   !
2780  ! ***********************************************************************
2790  ! Y MAXIMUM INCREASE
2800  ! ***********************************************************************
2810 Ymaxinc:Ymax=Ymax+.1
2820   GOSUB Plot
2830   GOTO G_idle
2840  !
2850  ! ***********************************************************************
2860  ! Y MAXIMUM DECREASE
2870  ! ***********************************************************************
2880 Ymaxdec:IF Ymax>=Ymin+.2 THEN Ymax=Ymax-.1
2890   GOSUB Plot
2900   GOTO G_idle
2910  !
2920  ! ***********************************************************************
2930  ! Y MINIMUM DECREASE
2940  ! ***********************************************************************
2950 Ymindec:Ymin=Ymin-.1
2960   GOSUB Plot
2970   GOTO G_idle
2980  !
2990  ! ***********************************************************************
3000  ! Y MINIMUM INCREASE
3010  ! ***********************************************************************
3020 Ymininc:IF Ymax>=Ymin+.2 THEN Ymin=Ymin+.1
3030   GOSUB Plot
3040   GOTO G_idle
3050  !
3060  ! **********************************************************************
3070  ! POINTS LINE
3080  ! **********************************************************************
3090 Points_line: !DETERMINES IF POINTS ARE TO BE PLOTTED OR JOINED WITH LINES
3100   IF Point_plot=1 THEN
3110      Point_plot=0
3120   ELSE
3130      Point_plot=1
3140   END IF
3150   BEEP
3160   RETURN
3170  !
3180  ! **********************************************************************
3190  ! PLOT
3200  ! **********************************************************************
3210 Plot:  !
3220   GCLEAR
3230   DEG
3240   GINIT
3250   CLIP ON
3260   VIEWPORT 15,130,13,90
3270   GRAPHICS ON
3280   FRAME
3290   WINDOW Xmin,Xmax,Ymin,Ymax
```

```
3300   IF Ymax-Ymin>=.50 THEN
3310      AXES .2,.1,Xmin,Ymin,5,5,2
3320   ELSE
3330      AXES .2,.02,Xmin,Ymin,5,5,2
3340   END IF
3350  !
3360   MOVE Xmin,0
3370   PLOT Xmax,0,-1                           ! DRAWS LINES AT (0,0)
3380   MOVE 0,Ymin
3390   PLOT 0,Ymax,-1
3400  !
3410   LDIR 0
3420   LORG 6                                   ! LABLES X-AXIS
3430   CSIZE 2.5
3440   CLIP OFF
3450   FOR X=Xmin TO Xmax
3460      IF ABS(X)<1.E-6 THEN X=0
3470      MOVE X,-.01*(Ymax-Ymin)+Ymin
3480      LABEL USING "K";X
3490 Next_x:NEXT X
3500  !
3510   CSIZE 3.5
3520   MOVE .5*(Xmax+Xmin),-.05*(Ymax-Ymin)+Ymin
3530   LABEL USING "K";"LOAD CELL OUTPUT (volts)"
3540  !
3550   CSIZE 2.5                                   ! LABLES Y-AXIS
3560   LORG 8
3570   !
3580   IF Ymax-Ymin>=2 THEN
3590      FOR Y=Ymin TO Ymax
3600         IF ABS(Y)<1.E-6 THEN Y=0
3610         MOVE -.015*(Xmax-Xmin)+Xmin,Y
3620         LABEL USING "K";Y
3630      NEXT Y
3640   ELSE
3650      IF Ymax-Ymin>=.50 THEN
3660         FOR Y=Ymin TO Ymax STEP .1
3670            IF ABS(Y)<1.E-6 THEN Y=0
3680            MOVE -.015*(Xmax-Xmin)+Xmin,Y
3690            LABEL USING "K";Y
3700 Next_y_1:NEXT Y
3710      ELSE
3720         FOR Y=Ymin TO Ymax STEP .02
3730            IF ABS(Y)<1.E-6 THEN Y=0
3740            MOVE -.015*(Xmax-Xmin)+Xmin,Y
3750            LABEL USING "K";Y
3760 Next_y_2:NEXT Y
3770      END IF
3780   END IF
3790  !
3800   LDIR 90
3810   LORG 4
3820   CSIZE 3.5
3830   MOVE -.07*(Xmax-Xmin)+Xmin,.5*(Ymax+Ymin)
3840   LABEL USING "K";Sig$(1,Sig)&Sig$(2,Sig)&" (volts)"
3850  !
3860   LDIR 0
3870   LORG 6                                             ! TITLES GRAPH
3880   MOVE .5*(Xmax+Xmin),Ymax+.10*(Ymax-Ymin)
3890   LABEL USING "K";Title$
3900  !
3910   MOVE .5*(Xmax+Xmin),Ymax+.05*(Ymax-Ymin)
3920   LABEL USING "K";Message_scale$                     ! TELLS GAINS USED
3930  !
3940   IF Sig>7 THEN RETURN
3950   LORG 5                                             ! PLOTS POINTS
```

```
3960  MOVE Rdgs(1,8)*.005,Rdgs(1,Sig)*.005
3970  CSIZE 2.0
3980  IF Point_plot THEN LABEL USING "K";"+"
3990  FOR I=2 TO Nscans
4000     IF Point_plot THEN
4010        MOVE Rdgs(I,8)*.005,Rdgs(I,Sig)*.005
4020        LABEL USING "K";"+"
4030     ELSE
4040        PLOT Rdgs(I,8)*.005,Rdgs(I,Sig)*.005,-1
4050     END IF
4060  NEXT I
4070 !
4080  CLIP ON
4090  MOVE Xmin,(Intercept(Sig)+Xmin/.005*Slope(Sig))*.005
4100  PLOT Xmax,(Intercept(Sig)+Xmax/.005*Slope(Sig))*.005,-1
4110  CLIP OFF
4120  DISP " SLOPE = ",Slope(Sig)
4130  !
4140  Position=1
4150  Next_time=0
4160 !
4170  RETURN
4180 !
4190 ! **********************************************************************
4200 ! EXIT
4210 ! **********************************************************************
4220 Exit:GCLEAR
4230   GOTO Driver
4240 !
4250 ! **********************************************************************
4260 ! LIST DATA
4270 ! **********************************************************************
4280 List_data: !
4290   OFF KEY
4300   ON KEY 5 LABEL "CONT",3 GOTO List_start
4310   ON KEY 9 LABEL "EXIT",3 GOTO Driver
4320   ON KEY 1 LABEL " ",3 GOTO Idle
4330   ON KEY 2 LABEL " ",3 GOTO Idle
4340   ON KEY 3 LABEL " ",3 GOTO Idle
4350   ON KEY 4 LABEL " ",3 GOTO Idle
4360   ON KEY 6 LABEL " ",3 GOTO Idle
4370   ON KEY 7 LABEL " ",3 GOTO Idle
4380   ON KEY 8 LABEL " ",3 GOTO Idle
4390   Start_line=1
4400   !
4410 ! **********************************************************************
4420 ! LIST START
4430 ! **********************************************************************
4440 List_start:   !
4450   PRINT CHR$(12)
4460   IF Message_scale$<>"" THEN
4470      PRINT Message_scale$
4480      PRINT
4490   END IF
4500   !
4510   IF Title$<>"" THEN PRINT Title$;"  Phi =";Phi;"  Theta =";Theta;"    ";Ti
me$;"  ";Date$
4520   GOSUB Print_header
4530   Lines=5
4540  !
4550   FOR I=Start_line TO Nscans
4560      GOSUB Print_volts
4570      IF Lines>=Form THEN New_page
4580   NEXT I
4590  !
4600  ! **********************************************************************
```

```
4610  ! NEW PAGE
4620  ! ***************************************************************
4630 New_page:IF I<Nscans THEN Start_line=I+1
4640    GOTO Idle
4650  !
4660  ! ***************************************************************
4670  ! PRINT HEADER
4680  ! ***************************************************************
4690 Print_header:  !
4700    PRINT
4710    PRINT "        ";
4720    FOR I=1 TO 8
4730       PRINT Sig$(1,I);
4740    NEXT I
4750    PRINT
4760    PRINT "        ";
4770    FOR I=1 TO 8
4780       PRINT Sig$(2,I);
4790    NEXT I
4800    PRINT USING "/"
4810    Lines=5
4820    RETURN
4830  !
4840  ! ***************************************************************
4850  ! PRINT VOLTS
4860  ! ***************************************************************
4870 Print_volts:  !
4880    PRINT USING "2X,DDD,2X,#";I
4890    FOR J=1 TO 8
4900       PRINT USING "X,MDD.DDD,1X,#";Rdgs(I,J)*.005
4910    NEXT J
4920    PRINT
4930    Lines=Lines+1
4940    RETURN
4950  !
4960  ! ***************************************************************
4970  ! SAVE DATA
4980  ! ***************************************************************
4990 Save_data:  !
5000    Time$=FNTime$(TIMEDATE)
5010    Date$=FNDate$(TIMEDATE)
5020    DISP Time$,Date$;
5030    INPUT "  ENTER TEST TITLE (80 char. max.)...",Title$
5040    INPUT "ENTER LOADING ANGLE RELATIVE TO RADIAL DIRECTION...",Phi
5050    INPUT "ENTER LOADING ANGLE RELATIVE TO CIRCUMFERENTIAL DIRECTION...",Thet
a
5060    INPUT "ENTER NAME OF OUTPUT DATA FILE...",File$
5070    Rec=(80+40+10+10+2+500*8*2)/256
5080    CREATE BDAT File$,Rec
5090    ASSIGN @Outfile TO File$
5100    OUTPUT @Outfile;Title$,Date$,Time$,Phi,Theta,Nscans,Rdgs(*)
5110    ASSIGN @Outfile TO *
5120    GOTO Driver
5130  !
5140  ! ***************************************************************
5150  ! GET DATA
5160  ! ***************************************************************
5170 Get_data:  !
5180    OFF KNOB
5190    OFF KEY
5200    Disk_read=0
5210    MASS STORAGE IS ":INTERNAL,4,0"
5220    ON ERROR GOSUB Other_disk
5230    IF All_cases THEN
5240       File$=Comp_tests$(Numb)
5250    ELSE
```

```
5260        INPUT "ENTER NAME OF DATA FILE TO BE READ...",File$
5270     END IF
5280     ASSIGN @Infile TO File$
5290     OFF ERROR
5300     ENTER @Infile;Title$,Date$,Time$,Phi,Theta,Nscans,Rdgs(*)
5310     ASSIGN @Infile TO *
5320     MASS STORAGE IS ":INTERNAL,4,0"
5330     !
5340     IF Change_gain THEN
5350        FOR I=1 TO Nscans
5360           FOR J=1 TO 6
5370              Rdgs(I,J)=INT(Rdgs(I,J)/5+.5)
5380           NEXT J
5390        NEXT I
5400     END IF
5410     !
5420     GOSUB Least_square
5430     DISP ""
5440     IF Slope_table THEN RETURN
5450     GOTO Graphics
5460   !
5470   ! *******************************************************************
5480   ! SCALE DATA
5490   ! *******************************************************************
5500 Scale_data:  ! CAN TREAT DATA TO AS IF IT HAD BEEN RECORDED AT LOWER GAIN
5510    IF Change_gain=0 THEN
5520       Change_gain=1
5530       Message_scale$=" AMPLIFIER GAINS USED ARE: CH1-6 400; CH7 1000; CH8 50
0 "
5540       DISP " DATA IS TREATED AS IF AMPLIFIER GAINS ARE THOSE USED DURING SHI
P TESTS"
5550    ELSE
5560       Change_gain=0
5570       Message_scale$=" AMPLIFIER GAINS USED ARE: CH1-6 2000; CH7 1000; CH8 5
00"
5580       DISP " DATA IS PRESENTED USING ACTUAL GAINS DURING CALIBRATION TESTS"
5590    END IF
5600    WAIT 2
5610    GOTO Driver
5620   ! *******************************************************************
5630   ! OTHER DISK
5640   ! *******************************************************************
5650 Other_disk:  ! CHECKS IF THE DISK INSERTED IS NOT THE CORRECT ONE
5660    IF ERRN=56 AND Disk_read=0 THEN
5670       MASS STORAGE IS ":INTERNAL,4,1"
5680       Disk_read=1
5690    ELSE
5700    !
5710       IF ERRN=56 AND Disk_read=1 THEN
5720          BEEP
5730          INPUT "ENTER NAME OF DATA FILE TO BE READ...AGAIN>>>",File$
5740          Disk_read=0
5750          MASS STORAGE IS ":INTERNAL,4,0"
5760       END IF
5770    !
5780       IF ERRN<>56 THEN
5790          MASS STORAGE IS ":INTERNAL,4,0"
5800          BEEP
5810          DISP "UNEXPECTED ERROR ",ERRN,"HAS OCCURED"
5820          MASS STORAGE IS ":INTERNAL,4,0"
5830          BEEP
5840          PAUSE
5850       END IF
5860    END IF
5870    RETURN
5880   !
```

```
5890  ! **************************************************************
5900  ! SET TIME
5910  ! **************************************************************
5920 Set_time:  !
5930   INPUT "ENTER CURRENT DATE (DD MMM YYYY)...",Date$
5940   SET TIMEDATE FNDate(Date$)
5950   INPUT "ENTER CURRENT TIME (HH:MM:SS)...",Time$
5960   SET TIME FNTime(Time$)
5970   RETURN
5980  !
5990  ! **************************************************************
6000  ! DISPLAY TIME
6010  ! **************************************************************
6020 Display_time:  !
6030   DISP FNTime$(TIMEDATE),FNDate$(TIMEDATE)
6040   RETURN
6050  !
6060  ! **************************************************************
6070  ! LEAST SQUARE FIT
6080  ! **************************************************************
6090 Least_square:  !
6100   DISP "CALCULATING BEST FIT LINES"
6110   Conversion=1
6120   FOR J=1 TO 7
6130      Sumx=0
6140      Sumy=0
6150      Sumxy=0
6160      Sumxsq=0
6170      FOR I=1 TO Nscans
6180         Xpoint=Rdgs(I,8)
6190         Ypoint=Rdgs(I,J)
6200         Sumx=Sumx+Xpoint
6210         Sumxsq=Sumxsq+Xpoint*Xpoint
6220         Sumy=Sumy+Ypoint
6230         Sumxy=Sumxy+Xpoint*Ypoint
6240      NEXT I
6250      Delta=Nscans*Sumxsq-Sumx*Sumx
6260      Slope(J)=Conversion*(Nscans*Sumxy-Sumx*Sumy)/Delta
6270      Intercept(J)=(Sumy*Sumxsq-Sumx*Sumxy)/Delta
6280      Value(J)=Slope(J)*10/(-1.366*.005)       ! mV OUTPUT/10kN LOAD USING
                                                     MEASURED CALIBRATION
6290  !   Value(J)=Slope(J)*1000/-7.22             ! mV. OUTPUT/kN LOAD USING
                                                     MANUFACTURES CALIBRATION
6300   NEXT J
6310  !
6320   IF Slope_table THEN RETURN
6330   PRINT Message_scale$
6340   PRINT ""
6350   PRINT Title$
6360   PRINT "   LEAST SQUARES BEST FIT VALUES"
6370   PRINT "FILE      GAGE      SLOPE     MEASURED "
6380   PRINT "NAME      NUMBER    BITS/BIT  mV/10kN  "
6390   PRINT
6400   FOR J=1 TO 7
6410      IF ABS(Slope(J))>999 OR ABS(Value(J))>999 THEN
6420         PRINT USING "8A,2X,2D,8X,MD.2DE,X,MD.2DE";File$,J,Slope(J),Value(J)
6430      ELSE
6440         PRINT USING "8A,2X,2D,8X,M3D.3D,3X,M3D.3D";File$,J,Slope(J),Value(J
)
6450      END IF
6460   NEXT J
6470   RETURN
6480  !
6490  ! **************************************************************
6500  ! MODIFIED LEAST SQUARE FIT
6510  ! **************************************************************
```

```
6520 Mod_least_sq:  ! FINDS BEST LINE THROUGH CHOOSEN POINTS
6530   Conversion=1
6540   Sumx=0
6550   Sumy=0
6560   Sumxy=0
6570   Sumxsq=0
6580   First_1=First
6590   Last_1=Last
6600   First=MIN(First_1,Last_1)
6610   Last=MAX(First_1,Last_1)
6620   IF First=0 OR Last=0 OR Last=First THEN
6630      BEEP
6640      DISP " YOU MUST CHOOSE THE LIMITS AGAIN"
6650   ELSE
6660      FOR I=First TO Last
6670         Xpoint=Rdgs(I,8)
6680         Ypoint=Rdgs(I,Sig)
6690         Sumx=Sumx+Xpoint
6700         Sumxsq=Sumxsq+Xpoint*Xpoint
6710         Sumy=Sumy+Ypoint
6720         Sumxy=Sumxy+Xpoint*Ypoint
6730      NEXT I
6740      Delta=(Last-First+1)*Sumxsq-Sumx*Sumx
6750      Mod_slope=Conversion*((Last-First+1)*Sumxy-Sumx*Sumy)/Delta
6760      Mod_intercept=(Sumy*Sumxsq-Sumx*Sumxy)/Delta
6770      LINE TYPE 1
6780      PEN 1
6790      MOVE Rdgs(First,8)*.005,(Mod_intercept+Mod_slope*Rdgs(First,8))*.005
6800      DRAW Rdgs(Last,8)*.005,(Mod_intercept+Mod_slope*Rdgs(Last,8))*.005
6810      DISP "SLOPE= ",Mod_slope
6820   END IF
6830   RETURN
6840   !
6850   ! *****************************************************************
6860   ! SLOPES
6870   ! *****************************************************************
6880 Slopes:  ! GIVES TABLE OF BEST FIT LINES FOR ALL GAGES IN ALL CASES
6890   Slope_table=1
6900   PRINTER IS 1
6910   Inpt$=""
6920   INPUT " DO YOU WANT HARD COPY : Y or CONT",Inpt$
6930   IF UPC$(Inpt$)="Y" THEN PRINTER IS 701
6940   Inpt$=""
6950   All_cases=0
6960   Numb=1
6970   INPUT " DO YOU WANT THE SLOPES FOR ALL CASES? : Y or CONT",Inpt$
6980   IF UPC$(Inpt$)="Y" THEN All_cases=1
6990 Next_page:PRINT CHR$(12)
7000   Lines=0
7010   PRINT Message_scale$
7020   PRINT
7030   PRINT "              GAGE OUTPUT VOLTAGE PER APPLIED LOAD ( mV/10kN ) "
7040   PRINT " TITLE      GAGE #1   GAGE #2   GAGE #3   GAGE #4   GAGE #5   GAGE
 #6   GAGE #7 "
7050 Next_slope:GOSUB Get_data
7060   IF MAX(Value(*))>999 OR MIN(Value(*))<-999 THEN
7070      PRINT USING Slope_eng;File$,Value(*)
7080 Slope_eng:IMAGE 10A,7(X,MD.2DE)
7090   ELSE
7100      PRINT USING Slope_output;File$,Value(*)
7110 Slope_output:IMAGE 10A,7(2X,M3D.3D)
7120   END IF
7130   !
7140   Lines=Lines+1
7150   IF NOT All_cases THEN
7160      Inpt$=""
```

```
7170        INPUT "DO YOU WANT ANOTHER FILE OUTPUT : N or CONT",Inpt$
7180        IF UPC$(Inpt$)="N" THEN Slopes_exit
7190        IF Lines<=50 THEN Next_slope
7200     ELSE
7210        Numb=Numb+1
7220        IF Numb>All_tests THEN Slopes_exit
7230        IF Lines<=50 THEN Next_slope
7240     END IF
7250     GOTO Next_page
7260   !
7270   ! ************************************************************
7280   ! SLOPES_EXIT
7290   ! ************************************************************
7300 Slopes_exit:  ! EXITS FROM SLOPES ROUTINE
7310     Slope_table=0
7320     PRINTER IS 1
7330     GOTO Driver
7340   !
7350   ! ************************************************************
7360   ! MOVE CURSOR
7370   ! ************************************************************
7380 Move_cursor:  !
7390     PEN 0
7400     LORG 5
7410     CSIZE 3.5
7420     IF Prev_knob$="LIN" AND Next_time THEN
7430        MOVE X_pos,Ymin
7440        DRAW X_pos,Ymax
7450        MOVE Xmin,Y_pos
7460        DRAW Xmax,Y_pos
7470     ELSE
7480        IF Next_time THEN
7490           MOVE X_pos,Y_pos
7500           LABEL "O"
7510        END IF
7520     END IF
7530     Next_time=1
7540     Prev_knob$="CUR"
7550     Position=Position+INT(KNOBX)
7560     IF Position<1 THEN Position=Nscans
7570     IF Position>Nscans THEN Position=1
7580     X_pos=Rdgs(Position,8)*.005
7590     Y_pos=Rdgs(Position,Sig)*.005
7600     MOVE X_pos,Y_pos
7610     LABEL "O"
7620     PEN 1
7630     Reading_sec=Position*.1
7640 P_list1:IMAGE DD.D," sec. X= ",2D.2D," Y= ",2D.2D
7650     DISP USING P_list1;Reading_sec,X_pos,Y_pos
7660     RETURN
7670   !
7680   ! ************************************************************
7690   ! MOVE LINES
7700   ! ************************************************************
7710 Move_lines:  !
7720     PEN 0
7730     LORG 5
7740     CSIZE 3.5
7750     IF Prev_knob$="CUR" AND Next_time THEN
7760        MOVE X_pos,Y_pos
7770        LABEL "O"
7780     ELSE
7790        IF Next_time THEN
7800           MOVE X_pos,Ymin
7810           DRAW X_pos,Ymax
7820           MOVE Xmin,Y_pos
```

```
7830        DRAW Xmax,Y_pos
7840     END IF
7850    END IF
7860  Next_time=1
7870  Prev_knob$="LIN"
7880  Position=Position+INT(KNOBX)
7890  IF Position<1 THEN Position=Nscans
7900  IF Position>Nscans THEN Position=1
7910  X_pos=Rdgs(Position,8)*.005
7920  Y_pos=Rdgs(Position,Sig)*.005
7930  MOVE X_pos,Ymin
7940  DRAW X_pos,Ymax
7950  MOVE Xmin,Y_pos
7960  DRAW Xmax,Y_pos
7970  PEN 1
7980  Reading_sec=Position*.1
7990  DISP USING P_list1;Reading_sec,X_pos,Y_pos
8000  PEN 0
8010  RETURN
8020  !
8030  ! ***********************************************************************
8040  ! LOWER LIMIT
8050  ! ***********************************************************************
8060 Lower_limit:   !
8070  First=Position
8080  RETURN
8090  !
8100  ! ***********************************************************************
8110  ! UPPER LIMIT
8120  ! ***********************************************************************
8130 Upper_limit:   !
8140  Last=Position
8150  RETURN
8160  !
8170  ! ***********************************************************************
8180  ! THE END
8190  ! ***********************************************************************
8200 The_end:   !
8210 !
8220  END
8230 !
8240 !
8250  DEF FNTime$(Now)
8260     Now=INT(Now) MOD 86400
8270     H=Now DIV 3600
8280     M=Now MOD 3600 DIV 60
8290     S=Now MOD 60
8300     OUTPUT T$ USING "#,ZZ,K";H,":",M,":",S
8310     RETURN T$
8320  FNEND
8330 !
8340  DEF FNTime(T$)
8350     ON ERROR GOTO Err
8360     ENTER T$;H,M,S
8370     RETURN (3600*H+60*M+S) MOD 86400
8380 Err: OFF ERROR
8390     RETURN TIMEDATE MOD 86400
8400  FNEND
8410 !
8420  DEF FNDate$(Seconds)
8430     DATA JAN,FEB,MAR,APR,MAY,JUN,JUL,AUG,SP,OCT,NOV,DEC
8440     DIM Month$(1:12)[3]
8450     READ Month$(*)
8460 !
8470     Julian=Seconds DIV 86400-1721119
8480     Year=(4*Julian-1) DIV 146097
```

```
8490      Julian=(4*Julian-1) MOD 146097
8500      Day=Julian DIV 4
8510      Julian=(4*Day+3) DIV 1461
8520      Day=(4*Day+3) MOD 1461
8530      Day=(Day+4) DIV 4
8540      Month=(5*Day-3) DIV 153
8550      Day=(5*Day-3) MOD 153
8560      Day=(Day+5) DIV 5
8570      Year=100*Year+Julian
8580      IF Month<10 THEN
8590         Month=Month+3
8600      ELSE
8610         Month=Month-9
8620         Year=Year+1
8630      END IF
8640      OUTPUT D$ USING "#,ZZ,X,3A,X,4Z";Day,Month$(Month),Year
8650      RETURN D$
8660   FNEND
8670  !
8680   DEF FNDate(Dmy$)
8690      DATA JAN,FEB,MAR,APR,MAY,JUN,JUL,AUG,SEP,OCT,NOV,DEC
8700      DIM Month$(1:12)[3]
8710      READ Month$(*)
8720  !
8730      ON ERROR GOTO Err
8740      I$=Dmy$&"     "
8750      ENTER I$ USING "DD,4A,5D,";Day,M$,Year
8760      IF Year<100 THEN Year=Year+1900
8770      FOR I=1 TO 12
8780         IF POS(M$,Month$(I)) THEN Month=I
8790      NEXT I
8800      IF Month=0 THEN Err
8810      IF Month>2 THEN
8820         Month=Month-3
8830      ELSE
8840         Month=Month+9
8850         Year=Year-1
8860      END IF
8870      Century=Year DIV 100
8880      Remainder=Year MOD 100
8890      Julian=146097*Century DIV 4+1461*Remainder DIV 4+(153*Month+2) DIV 5+D
ay+1721119
8900      Julian=Julian*86400
8910      IF Julian<2.08662912E+11 OR Julian>=2.143252224E+11 THEN Err
8920      RETURN Julian
8930 Err: OFF ERROR
8940      RETURN TIMEDATE
8950   FNEND
```

```
10    ! PROGRAM "BLADE_CAL3"
20    ! VERSION : 3.00
30    ! MODEL OF INSTRUMENTED PROPELLER BLADE ON ROBERT LEMEUR
40    ! DESIGNED TO GIVE OUTPUT PARAMATERS FOR A UNIT LOAD ON THE BLADE
50    ! AT ANY OF THE CALIBRATION POINTS
60    !
70    ! WRITTEN BY : KEN KIRBY
80    ! DATE : 84-10-01
90    !
100   ! MODIFIED BY: KEN KIRBY
110   ! DATE : 84-11-09
120   ! REASON : TO ADD CASES 6 AND 7 & POINTS 37 AND 38
130   !
140   ! MODIFIED BY: KEN KIRBY
150   ! DATE : 84-12-21
160   ! REASON : TO ALLOW PLOTTING OF MEASURED SLOPES VERSES DIFFERENT
170   !          PARAMATERS
180   !
190   ! MODIFIED BY: KEN KIRBY
200   ! DATE : 85-01-27
210   ! REASON : TO ADD HYSTERESIS DATA
220   !          TO ALLOW PLOTTING OF TABLE WITH MISSING DATA
230   !
240   ! MODIFIED BY: KEN KIRBY
250   ! DATE : 85-01-30
260   ! REASON : TO SCALE MEASURED SLOPES TO THE CALCULATED SLOPE
270   !
280   ! MODIFIED BY:
290   ! DATE :
300   ! REASON :
310   !
320    OPTION BASE 1
330    DEG
340    DIM Comp_tests$(50)[10]
350    DIM Rel_rad(38),Rel_circ(38),Horiz_angle(7),Vert_angle(7)
360    DIM Blk_slope(50),Hysteresis(50)
370    INTEGER Friction
380    !
390    DIM Title$[80]
400    DIM Message$[37]
410    INTEGER I,J,K,L,M,N,X_col,Y_col,Col,Row,Any_data,First,Last
420    INTEGER Crt_rows,Page_rows,Lines,Start_line,Hard_copy
430    REAL Sumx,Sumxsq,Sumy,Sumxy,Xpoint,Ypoint
440    DIM Data_message$[17]
450    !
460    Col=17
470    Row=50
480    !
490    ALLOCATE Name1$(Col)[8],Name2$(Col)[8],Units$(Col)[8]
500    ALLOCATE INTEGER Use_data(Row)
510    ALLOCATE REAL Gain(Col),Offset(Col)
520    ALLOCATE REAL Table(Row,Col)
530   !
540    Version_no$="2.00"
550    Friction=1
560    Crt_rows=10
570    Page_rows=50
580    First=1
590    Last=Row
600   !
610    MAT Use_data= (1)
620    MAT Table= (-1.E+6)
630    Any_data=0
640    I$=CHR$(129)
650    N$=CHR$(120)
660   !
```

```
670    ! ******************************************************************************
680    ! MAIN PROGRAM
690    ! ******************************************************************************
700 Main:    !
710     ON ERROR GOTO Error_fix
720     GOSUB Friction_test
730     GOSUB Read_data
740 Start_driver:    !
750     PRINTER IS 1
760     Hard_copy=0
770     GOSUB Driver
780 Nowhere:GOTO Nowhere
790     !
800    ! ****************************************************************************
810    ! DRIVER
820    ! ****************************************************************************
830 Driver:  !
840     OFF KNOB
850     OFF KEY
860     ON KEY 1 LABEL "" GOSUB Idle
870     ON KEY 2 LABEL "LOCATION",3 GOSUB Location
880     ON KEY 3 LABEL "CASES",3 GOSUB Cases
890     ON KEY 4 LABEL "" GOSUB Idle
900     ON KEY 5 LABEL "PLOT DATA",3 GOTO Fill_table
910     ON KEY 6 LABEL "" GOSUB Idle
920     ON KEY 7 LABEL "" GOSUB Idle
930     ON KEY 8 LABEL "FRICTION",3 GOSUB Friction_test
940     ON KEY 9 LABEL "CALC. SIGNALS",3 GOSUB Calc_signals
950     RETURN
960   !
970  !
980   ! ******************************************************************************
990   ! IDLE
1000 ! ******************************************************************************
1010 Idle:RETURN
1020      !
1030 ! ******************************************************************************
1040 ! ERROR FIX
1050 ! ****************************************************************************
1060 Error_fix: !
1070   DISP I$;ERRM$;N$
1080   BEEP
1090   OFF ERROR
1100   GOTO Start_driver
1110            !
1120  ! *****************************************************************************
1130  ! FRICTION_TEST DETERMINES IF FRICTION IS INCLUDED IN THE CALCULATIONS
1140  ! *****************************************************************************
1150 Friction_test:  !
1160   IF Friction=0 THEN
1170      Message$="FRICTION INCLUDED IN CALCULATIONS"
1180      Friction=1
1190  ! FRICTION_TORQUE=AVERAGE S.B OFFSET/2*S.B. GAIN*(S.B.LEVER ARM + TRAVEL)
1200      Friction_torque=3.3                        ! kN.m
1210   ELSE
1220      Message$="FRICTION NOT INCLUDED IN CALCULATIONS"
1230      Friction=0
1240      Friction_torque=0
1250   END IF
1260   DISP I$;Message$;N$
1270   BEEP
1280   RETURN
1290  !
1300  ! *****************************************************************************
1310  ! READ_DATA READS THE BLADE CONSTANTS
1320  ! *****************************************************************************
```

```
1330 Read_data:  !
1340  !
1350   Blade_size=1.5                      ! meters RADIUS
1360   Pitch=-23.4                         ! deg. DURING CALIBRATIONS
1370   !
1380   Title$="CALIBRATION OF SLIDING BLOCK"
1390  !
1400  !     RELATIVE RADIUS OF POINTS
1410  !
1420 Radius_data: !
1430   DATA .98,.98,.98,.98,.98,.98,.98
1440   DATA .9,.9,.9,.9,.9,.9,.9
1450   DATA .8,.8,.8,.8,.8,.8,.8
1460   DATA .7,.7,.7,.7,.7,.7,.7
1470   DATA .6,.6,.6,.6,.6,.6
1480   DATA .5,.5,1,.9
1490   RESTORE Radius_data
1500   READ Rel_rad(*)
1510  !
1520   Force=1                            ! APPLIED FORCE kN
1530  !
1540  !      RELATIVE CIRCUMFERENCE OF POINTS
1550  !
1560 Circ_data: !
1570   DATA .05,.15,.25,.35,.5,.75,.95
1580   DATA .05,.15,.25,.35,.5,.75,.95
1590   DATA .05,.15,.25,.35,.5,.75,.95
1600   DATA .05,.15,.25,.35,.5,.75,.95
1610   DATA .05,.15,.25,.35,.75,.95
1620   DATA .06,.5,.15,1
1630   RESTORE Circ_data
1640   READ Rel_circ(*)
1650  !
1660  !      HORIZONTAL ANGLES FOR LOAD CASES
1670  !
1680 Horz_angle: !
1690   DATA -27.4,-39.4,-15.4,-27.4,-27.4,-23.4,-122.8
1700   RESTORE Horz_angle
1710   READ Horiz_angle(*)
1720  !
1730  !      VERTICAL ANGLES FOR LOAD CASES
1740  !
1750 Vertical_angle: !
1760   DATA 0,0,0,-12,12,-90,1.4
1770   RESTORE Vertical_angle
1780   READ Vert_angle(*)
1790   !
1800   ! ACTUAL GAIN CONVERTED USING: (SL_BLK=122kN/V) / (LOAD CELL=-7.22kN/V)
1810   ! GAVE -16.9 , HOWEVER WILL USE TWO GAINS :
1820   ! FOR POSITIVE SLOPES GAIN=(178 kN/VOLT)/(-7.22kN/V)=-24.65
1830   ! FOR NEGATIVE SLOPES GAIN=(48.8 kN/VOLT)/(-7.22kN/V)=-6.76
1840   Alt_gain=-6.76
1850   Alt_offset=0
1860 Gain_data:  !
1870   DATA 1,1,1,1,1,1,1,-24.65,1,7.22,1,1,1,1,1,1,1
1880   RESTORE Gain_data
1890   READ Gain(*)
1900   !
1910 Offset_data:  !
1920   DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
1930   RESTORE Offset_data
1940   READ Offset(*)
1950   !
1960 Name_data:  !
1970   DATA "POINT","CASE","REL.","DIST.FRM","REL."
1980   DATA "DIST.FRM","CALC.","ACTUAL","CAL/ACT","HYS."
```

```
1990   DATA "HYS/CALC","HYS/ACT","HYS*CALC","HYS*ACT","HYS/DIS."
2000   DATA "HYS*DIS.","SPIN.TQ"
2010   RESTORE Name_data
2020   READ Name1$(*)
2030   DATA "NUMBER","NUMBER","RADIUS","FOOT","CIRC."
2040   DATA "C.L.","SLOPE","SLOPE","SLOPE",""
2050   DATA "SLOPE","SLOPE","SLOPE","SLOPE","FRM.CEN."
2060   DATA "FRM.CEN.","HYS."
2070   READ Name2$(*)
2080   !
2090 Units_data:  !
2100   DATA "","","m/m","m","m/m"
2110   DATA "m","kN/kN","kN/kN","","kN"
2120   DATA "kN","kN","kN","kN","kN/m"
2130   DATA "kN.m","kN.m"
2140   RESTORE Units_data
2150   READ Units$(*)
2160   !
2170 Comp_test_names:  !
2180   DATA "PT1_C2    ","PT1_C3    ","PT2_C1    ","PT2_C1_2  ","PT2_C2    "
2190   DATA "PT2_C3    ","PT4_C2    ","PT4_C3    ","PT4_C5    ","PT5_C3    "
2200   DATA "PT5_C5    ","PT7_C2    ","PT7_C3    ","PT7_C4    ","PT8_C3    "
2210   DATA "PT9_C2    ","PT9_C3    ","PT2_C3_2  ","PT10_C2   ","PT10_C3   "
2220   DATA "PT10_C4   ","PT11_C2   ","PT11_C4   ","PT12_C2   ","PT12_C2_2 "
2230   DATA "PT12_C3   ","PT15_C2   ","PT15_C3   ","PT17_C2   ","PT17_C3   "
2240   DATA "PT19_C3   ","PT20_C3   ","PT21_C2   ","PT22_C2   ","PT22_C3   "
2250   DATA "PT24_C2   ","PT24_C3   ","PT24_C4   ","PT24_C5   ","PT25_C2   "
2260   DATA "PT25_C3   ","PT29_C2   ","PT29_C3   ","PT30_C2   ","PT31_C2   "
2270   DATA "PT32_C2   ","PT32_C3   ","PT33_C3   ","PT34_C2   ","PT35_C2   "
2280   RESTORE Comp_test_names
2290   READ Comp_tests$(*)
2300   !
2310 All_slope_data:  ! SLOPES USING ALL POINTS RECORDED
2320   DATA .0732,.0479,.0488,.0397,.0479
2330   DATA .0394,.0352,-.001,.0309,-.0041
2340   DATA .0106,-.205,-.236,-.2006,.0578
2350   DATA .0482,.0594,.0375,.0538,.0309
2360   DATA .0207,.0366,.0234,.0044,.0015
2370   DATA -.004,.0814,.0553,.0364,.0194
2380   DATA -.0043,-.059,-.2393,.0532,.07
2390   DATA .0431,.0123,.0352,.0195,.024
2400   DATA .0028,.0268,.0282,.0306,.03319
2410   DATA .0179,-.0009,-.0473,-.1732,.0227
2420   ! RESTORE All_slope_data
2430   !
2440 Sel_slope_data:  !   . SLOPES USING SELECTED POINTS FROM DATA (SLOPE 2)
2450   DATA .106,.0525,.0844,.0647,.0642
2460   DATA .052,.0938,-.001,.0346,-.0041
2470   DATA -.0106,-.294,-.273,-.33,.113
2480   DATA .0818,.0997,.053,.1048,.0779
2490   DATA .075,.0741,.075,.0044,.007
2500   DATA -.016,.12,.092,.062,.04
2510   DATA -.004,-.13,-.319,.0984,.14
2520   DATA .11,.067,.0763,.083,.0466
2530   DATA .0173,.0777,.0968,.1324,.078
2540   DATA .0618,.0099,-.1074,-.2927,.0632
2550   RESTORE Sel_slope_data
2560   !
2570 Sel_good_slope: !SLOPES USING SELECTED POINTS FROM DATA (SLOPE 2) >HYS VOLT
2580   DATA .106,.081,.077,.061,.066
2590   DATA .052,-1E6,-1E6,-1E6,-1E6
2600   DATA -1E6,-.294,-.448,-.335,.099
2610   DATA .082,-1E6,-1E6,-1E6,-1E6
2620   DATA -1E6,-1E6,-1E6,-1E6,-1E6
2630   DATA -1E6,.120,.090,.055,-1E6
2640   DATA -1E6,-.127,-.321,.100,-1E6
```

```
2650    DATA -1E6,-1E6,-1E6,-1E6,-1E6
2660    DATA -1E6,.070,.067,-1E6,-1E6
2670    DATA -1E6,-1E6,-.114,-.294,.063
2680    RESTORE Sel_good_slope
2690    READ Blk_slope(*)
2700    !
2710 Hys_data:  !     HYSTERESIS CHANGE IN VOLTAGE OF LOAD CELL FOR SAME SB SIG.
2720    DATA 2.05,.83,.84,.63,1.44
2730    DATA -1E6,1.12,0,.820,0
2740    DATA 0,-1E6,1.66,2.66,1.83
2750    DATA 1.39,2.37,-1E6,1.68,.96
2760    DATA 1.14,1.08,1.49,0,0
2770    DATA 0,2.66,2.71,1.79,1.04
2780    DATA -1E6,-1E6,1.26,2.92,2.17
2790    DATA 2.24,1.95,2.03,1.43,1.75
2800    DATA 0,3.3,3.16,2.04,-1E6
2810    DATA 2.9,0,2.46,2.56,3.85
2820    RESTORE Hys_data
2830    READ Hysteresis(*)
2840    RETURN
2850   !
2860   ! ************************************************************************
2870   ! HARDCOPY DETERMINES IF A PRINTOUT ON PAPER IS REQUIRED
2880   ! ************************************************************************
2890 Hardcopy:  !
2900    PRINTER IS 1
2910    Hard_copy=0
2920    Inpt$=""
2930    DISP "DO YOU WANT A HARD COPY , INPUT : ";I$;"Y";N$;" or ";I$;"CONT";N$;
2940    INPUT Inpt$
2950    IF UPC$(Inpt$[1,1])="Y" THEN
2960       PRINTER IS 701
2970       Hard_copy=1
2980    END IF
2990    RETURN
3000   !
3010   ! ***********************************************************************
3020   ! LISTING DETERMINES IF YOU WANT SINGLE POINTS OR ALL CASES
3030   ! ***********************************************************************
3040 Calc_signals:  !
3050    Combinations$=""
3060    GOSUB Hardcopy
3070    GOSUB Heading
3080    INPUT "TO GET ALL POSSIBLE COMBINATIONS INPUT : A or CONT",Combinations$
3090    IF UPC$(Combinations$)="A" THEN
3100       FOR Case=1 TO 5
3110          FOR Point=1 TO 36
3120             IF Hard_copy THEN
3130                IF Lines=Page_rows THEN GOSUB Heading
3140             ELSE
3150                IF Lines=Crt_rows THEN GOSUB Heading
3160             END IF
3170             GOSUB Calculate
3180             GOSUB Printout
3190          NEXT Point
3200       NEXT Case
3210       Case=6
3220       Point=37
3230       IF Hard_copy THEN
3240          IF Lines=Page_rows THEN GOSUB Heading
3250       ELSE
3260          IF Lines=Crt_rows THEN GOSUB Heading
3270       END IF
3280       GOSUB Calculate
3290       GOSUB Printout
3300       Case=7
```

```
3310      Point=38
3320      IF Hard_copy THEN
3330         IF Lines=Page_rows THEN GOSUB Heading
3340      ELSE
3350         IF Lines=Crt_rows THEN GOSUB Heading
3360      END IF
3370      GOSUB Calculate
3380      GOSUB Printout
3390   ELSE
3400 Again:GOSUB Next_point
3410      IF Point<>0 THEN
3420         GOSUB Calculate
3430         GOSUB Printout
3440         GOTO Again
3450      END IF
3460  !
3470   END IF
3480   PRINTER IS 1
3490   Hard_copy=0
3500   RETURN
3510  !
3520  ! **********************************************************************
3530  ! HEADING PLACES HEADINGS ON PAGES
3540  ! **********************************************************************
3550 Heading:   !
3560   Lines=0
3570   PRINT CHR$(12)
3580   PRINT TAB(10),Message$;"    ";"VERSION ";Version_no$
3590   PRINT
3600   PRINT " ******************************************************************
**************"
3610   PRINT " LOAD     LOAD      IN PLANE  OUT PLANE IN PLANE  OUT PLANE SLIDIN
G   SERVO OIL "
3620   PRINT " POINT    CASE      FORCE     FORCE     BENDING   BENDING   BLK FO
RCE PRESSURE  "
3630   PRINT " NUMBER   NUMBER    kN/kN     kN/kN     kNm/kN    kNm/kN    kN/kN
   kPa/kN    "
3640   PRINT " ******************************************************************
**************"
3650   PRINT
3660   RETURN
3670  !
3680  ! **********************************************************************
3690  ! NEXT_POINT ASKS FOR THE NEXT POINT TO BE ENTERED MANUALLY
3700  ! **********************************************************************
3710 Next_point:   !  ASKS FOR POINTS TO PRINT
3720   IF Hard_copy THEN
3730      IF Lines=Page_rows THEN GOSUB Heading
3740   ELSE
3750      IF Lines=Crt_rows THEN GOSUB Heading
3760   END IF
3770   Point=0
3780 Re_enter_point:INPUT "INPUT POINT AND LOAD CASE AT WHICH LOAD IS APPLIED :
Point,Case",Point,Case
3790   IF Point<0 OR Point>38 OR Case<1 OR Case>7 THEN
3800      BEEP
3810      DISP I$;"RE-";N$;
3820      GOTO Re_enter_point
3830   END IF
3840   RETURN
3850  !
3860  ! **********************************************************************
3870  ! CALCULATE DETERMINES THE EXPECTED ENGINEERING UNIT OUTPUTS
3880  ! **********************************************************************
3890 Calculate:  !
3900   Radius=Rel_rad(Point)*Blade_size
```

```
3910   Delta_pitch=-42.27393*Rel_rad(Point)^3+120.2007*Rel_rad(Point)^2-130.7025
*Rel_rad(Point)+47.0934
3920   Chord_length=-12.759664*Rel_rad(Point)^4+28.0955*Rel_rad(Point)^3-22.9033
6*Rel_rad(Point)^2+9.82259*Rel_rad(Point)-1.0154524
3930   Chord=Chord_length*(Rel_circ(Point)-.5)
3940   Epislon=Chord*360/(2*PI*Radius)
3950   !
3960   !    LOCATION OF LOAD
3970   !
3980   Lever_arm=Radius*SIN(Epislon)
3990   X_coord=Lever_arm*COS(Pitch+Delta_pitch)
4000   Y_coord=Radius*COS(Epislon)-.44
4010   Z_coord=Lever_arm*SIN(Pitch+Delta_pitch)
4020   !
4030   !    COMPONENTS OF FORCE
4040   !
4050   X_force=-Force*SIN(Horiz_angle(Case))*COS(Vert_angle(Case))
4060   Y_force=-Force*COS(Horiz_angle(Case))*SIN(Vert_angle(Case))
4070   Z_force=-Force*COS(Horiz_angle(Case))*COS(Vert_angle(Case))
4080   !
4090   !    CALCULATED QUANTITIES
4100   !
4110   Spindle_torque=-(X_force*Z_coord+Z_force*X_coord)       ! kNm
4120   IF Friction THEN
4130     IF ABS(Spindle_torque)<Friction_torque THEN
4140       Spindle_torque=0
4150     ELSE
4160       IF Spindle_torque>0 THEN
4170         Spindle_torque=Spindle_torque-Friction_torque
4180       ELSE
4190         Spindle_torque=Spindle_torque+Friction_torque
4200       END IF
4210     END IF
4220   END IF
4230   Block_load=Spindle_torque*COS(Pitch-5)/.208                    ! kN
4240   Oil_pressure=-Block_load*COS(Pitch-5)/15.9                     ! BAR INCREASE DUE TO
                                                                        ONE BLADE
4250   Plane_angle=Pitch-42.27393*.47^3+120.2007*.47^2-130.7025*.47+47.0934
4260   In_plane_force=X_force*COS(Plane_angle)-Z_force*SIN(Plane_angle)
4270   Out_plane_force=-X_force*SIN(Plane_angle)-Z_force*COS(Plane_angle)
4280   In_plane_bend=In_plane_force*Y_coord
4290   Out_plane_bend=Out_plane_force*Y_coord
4300   !
4310   RETURN
4320   !
4330   ! ***************************************************************
4340   ! PRINTOUT LISTS THE OUTPUT VALUES
4350   ! ***************************************************************
4360 Printout:  !
4370   PRINT USING P_list1;Point,Case,In_plane_force,Out_plane_force,In_plane_be
nd,Out_plane_bend,Block_load,Oil_pressure
4380 P_list1:IMAGE 4X,DD,8X,DD,2X,6(4X,MD.DDD)
4390   Lines=Lines+1
4400   RETURN
4410   !
4420   ! ***************************************************************
4430   ! LOCATION OF LOAD POINTS
4440   ! ***************************************************************
4450 Location:   !
4460   PRINTER IS 1
4470   GOSUB Hardcopy
4480   PRINT CHR$(10)
4490   PRINT "                    CALIBRATION POINT LOCATIONS ON THE AFT SIDE"
4500   PRINT "                    OF THE INSTRUMENTED PROPELLER BLADE"
4510   PRINT
4520   PRINT "                    POINT          RELATIVE        RELATIVE"
```

```
4530   PRINT "                          NUMBER          RADIUS          CHORD"
4540   PRINT
4550   FOR I=1 TO 38
4560      PRINT USING "15X,DD,7X,2(8X,3D.3D)";I,Rel_rad(I),Rel_circ(I)
4570   NEXT I
4580   PRINT CHR$(10)
4590   PRINT "                The relative chord is zero at the leading edge of"
4600   PRINT "                the blade and one at the trailing edge of the blade."
4610   PRINT "                The relative radius is zero at the center of the hub"
4620   PRINT "                and one at the tip of the blade."
4630   Hard_copy=0
4640   PRINTER IS 1
4650   RETURN
4660   !
4670   ! *******************************************************************
4680   ! CASES OF LOADING ANGLES
4690   ! *******************************************************************
4700 Cases:  !
4710   PRINTER IS 1
4720   GOSUB Hardcopy
4730   PRINT "                  LOAD CASE ANGLES FOR THE VARIOUS LOAD CASES"
4740   PRINT
4750   PRINT "                  LOAD CASE       HORIZONTAL      VERTICAL"
4760   PRINT "                  NUMBER          ANGLE           ANGLE"
4770   PRINT
4780   FOR I=1 TO 7
4790      PRINT USING "15X.DD,7X,2(8X,3D.3D)";I,Horiz_angle(I)-Pitch,Vert_angle(
I)
4800   NEXT I
4810   PRINT "                  For the calibration tests, the blade is positioned"
4820   PRINT "                  such that the tip of the blade is pointing down,"
4830   PRINT "                  (i.e. below the hub )."
4840   PRINT "                  The horizontal angle is the number of degrees"
4850   PRINT "                  in the horizontal plane, by which the angle of"
4860   PRINT "                  load application varies from perpendicular to"
4870   PRINT "                  the blade at 0.47 relative radius. Positive"
4880   PRINT "                  towards the leading edge."
4890   PRINT "                  The vertical angle is the number of degrees in"
4900   PRINT "                  the vertical plane, by which the angle of load"
4910   PRINT "                  application varies from perpendicular to the"
4920   PRINT "                  blade. Positive upwards."
4930   Hard_copy=0
4940   PRINTER IS 1
4950   RETURN
4960   !
4970 !
4980 ! *******************************************************************
4990 ! FILL_TABLE
5000 ! *******************************************************************
5010 Fill_table:!
5020   MAT Use_data= (1)
5030   Data_message$="ALL DATA USED"
5040   DISP I$;Data_message$;N$
5050   IF NOT Any_data THEN
5060      DISP I$;"HOLD ON .... THIS MAY TAKE A WHILE";N$
5070      OFF KEY
5080      OFF KNOB
5090      FOR I=1 TO Row
5100         IF UPC$(Comp_tests$(I)[5,5])="C" THEN
5110            Point=VAL(Comp_tests$(I)[3,3])
5120            Case=VAL(Comp_tests$(I)[6,6])
5130         ELSE
5140            Point=VAL(Comp_tests$(I)[3,4])
5150            Case=VAL(Comp_tests$(I)[7,7])
5160         END IF
5170         GOSUB Calculate
```

```
5180         Table(I,1)=Point*Gain(1)+Offset(1)
5190         Table(I,2)=Case*Gain(2)+Offset(2)
5200         Table(I,3)=Rel_rad(Point)*Gain(3)+Offset(3)
5210         Table(I,4)=Y_coord*Gain(4)+Offset(4)
5220         Table(I,5)=Rel_circ(Point)*Gain(5)+Offset(5)
5230         Table(I,6)=Lever_arm*Gain(6)+Offset(6)
5240         Table(I,7)=Block_load*Gain(7)+Offset(7)
5250         IF Blk_slope(I)<>-1.E+6 THEN
5260            IF Blk_slope(I)<0 THEN
5270               Table(I,8)=Blk_slope(I)*Alt_gain+Alt_offset
5280            ELSE
5290               Table(I,8)=Blk_slope(I)*Gain(8)+Offset(8)
5300            END IF
5310         END IF
5320         IF Table(I,7)=0 THEN
5330            Table(I,8)=0
5340            Table(I,9)=0
5350         ELSE
5360            Table(I,9)=Table(I,7)/Table(I,8)
5370         END IF
5380         IF Blk_slope(I)=-1.E+6 THEN Hysteresis(I)=-1.E+6
5390         IF Hysteresis(I)<>-1.E+6 THEN
5400            Table(I,10)=Hysteresis(I)*Gain(10)+Offset(10)
5410            IF Table(I,7)<>0 THEN Table(I,11)=Table(I,10)/Table(I,7)
5420            IF Table(I,8)<>0 THEN Table(I,12)=Table(I,10)/Table(I,8)
5430            Table(I,13)=Table(I,10)*Table(I,7)
5440            Table(I,14)=Table(I,10)*Table(I,8)
5450            IF Table(I,6)<>0 THEN Table(I,15)=Table(I,10)/Table(I,6)
5460            Table(I,16)=Table(I,10)*Table(I,6)
5470         END IF
5480      NEXT I
5490      DISP I$;"NOT MUCH LONGER NOW ...";N$
5500      Temp_frict=Friction
5510      Friction=0
5520      FOR I=1 TO Row
5530         IF Hysteresis(I)<>-1.E+6 THEN
5540            Force=Table(I,10)
5550            IF UPC$(Comp_tests$(I)[5,5])="C" THEN
5560               Point=VAL(Comp_tests$(I)[3,3])
5570               Case=VAL(Comp_tests$(I)[6,6])
5580            ELSE
5590               Point=VAL(Comp_tests$(I)[3,4])
5600               Case=VAL(Comp_tests$(I)[7,7])
5610            END IF
5620            GOSUB Calculate
5630            Table(I,17)=ABS(Spindle_torque)
5640         END IF
5650      NEXT I
5660      Friction=Temp_frict
5670      Any_data=1
5680      DISP I$;"PICK A KEY ... ANY KEY ... EVERYONE IS A WINNER";N$
5690   END IF
5700   GOTO Graphics_keys
5710            !
5720 ! ************************************************************************
5730 ! GRAPHICS KEYS
5740 ! ************************************************************************
5750 Graphics_keys: !
5760              !
5770   DUMP DEVICE IS 701,EXPANDED
5780   OFF KNOB
5790   OFF KEY
5800   ON KEY 0 LABEL "Xscale INC/DEC",3 GOSUB Xscaleinc
5810   ON KEY 10 GOSUB Xscaledec
5820   ON KEY 1 LABEL "Yscale INC/DEC",3 GOSUB Yscaleinc
5830   ON KEY 11 GOSUB Yscaledec
```

```
5840   ON KEY 2 LABEL "PLOT.LS/DUMP G",3 GOSUB Plot_least_sq
5850   ON KEY 12 GOSUB Dump_graphics
5860   ON KEY 3 LABEL "LABEL UP/DOWN",3 GOSUB Label_up
5870   ON KEY 13 GOSUB Label_down
5880   ON KEY 4 LABEL "Plot/PT.LINE",3 GOSUB Graphics
5890   ON KEY 14 GOSUB Points_line
5900   ON KEY 5 LABEL "Xmin INC/DEC",3 GOSUB Xmininc
5910   ON KEY 15 GOSUB Xmindec
5920   ON KEY 6 LABEL "Ymin INC/DEC",3 GOSUB Ymininc
5930   ON KEY 16 GOSUB Ymindec
5940   ON KEY 7 LABEL "FST/LAST POINT",3 GOSUB First_point
5950   ON KEY 17 GOSUB Last_point
5960   ON KEY 8 LABEL "DEL/ALL POINTS",3 GOSUB Delete_point
5970   ON KEY 18 GOSUB All_points
5980   ON KEY 9 LABEL "EXIT/LIST DATA",3 GOTO Exit_graphics
5990   ON KEY 19 GOTO List_data
6000 Stay_here:GOTO Stay_here
6010 !
6020 ! ******************************************************************
6030 ! GRAPHICS
6040 ! ******************************************************************
6050 Graphics: !
6060   GCLEAR
6070   OFF KNOB
6080   PRINTER IS 1
6090   Hard_copy=0
6100   Join$=""
6110 Re_enter_x:INPUT "ENTER CHANNEL # TO BE PLOTTED ON X AXIS: X_col",X_col
6120   IF X_col<1 OR X_col>Col THEN
6130      DISP I$;"RE-";N$;
6140      BEEP
6150      GOTO Re_enter_x
6160   END IF
6170 Re_enter_y:INPUT "ENTER CHANNEL # TO BE PLOTTED ON Y AXIS: Y_col",Y_col
6180   IF Y_col<1 OR Y_col>Col THEN
6190      DISP I$;"RE-";N$;
6200      BEEP
6210      GOTO Re_enter_y
6220   END IF
6230   Xmin=1.E+6
6240   Ymin=1.E+6
6250   Xmax=-1.E+6
6260   Ymax=-1.E+6
6270   Counter=0
6280   FOR I=First TO Last
6290      IF Use_data(I) THEN
6300         IF Table(I,X_col)=-1.E+6 OR Table(I,Y_col)=-1.E+6 THEN
6310            Use_data(I)=0
6320            Counter=Counter+1
6330         ELSE
6340            Xmin=MIN(Xmin,Table(I,X_col))
6350            Ymin=MIN(Ymin,Table(I,Y_col))
6360            Xmax=MAX(Xmax,Table(I,X_col))
6370            Ymax=MAX(Ymax,Table(I,Y_col))
6380         END IF
6390      END IF
6400   NEXT I
6410   IF Counter>0 THEN
6420      Data_message$="NOT ALL DATA USED"
6430      DISP I$;Counter;" NON AVAILABLE POINTS DELETED";N$
6440      BEEP
6450      WAIT 2
6460   END IF
6470   Xmin=INT(Xmin)
6480   Ymin=INT(Ymin)
6490   Xmax=INT(Xmax+1)
```

```
6500   Ymax=INT(Ymax+1)
6510   Xscale=ABS(Xmax-Xmin)
6520   Yscale=ABS(Ymax-Ymin)
6530   Xmin=MIN(Xmin,Xmax)
6540   Ymin=MIN(Ymin,Ymax)
6550   PRINT CHR$(12)
6560   GOSUB Plot
6570   ON KNOB .1,9 GOSUB Move_cursor
6580   RETURN
6590  !
6600  ! ***********************************************************************
6610  ! EXIT_GRAPHICS
6620  ! ***********************************************************************
6630 Exit_graphics:   !
6640   GRAPHICS OFF
6650   OFF KNOB
6660   GOTO Start_driver
6670  !
6680  ! ***********************************************************************
6690  ! X SCALE INCREASE
6700  ! ***********************************************************************
6710 Xscaleinc:!
6720   IF Xscale<.1 THEN
6730      Xscale=INT((Xscale+.001)*1000)/1000
6740   ELSE
6750      IF Xscale<1 THEN
6760         Xscale=INT((Xscale+.01)*100)/100
6770      ELSE
6780         IF Xscale<10 THEN
6790            Xscale=INT((Xscale+.1)*10)/10
6800         ELSE
6810            IF Xscale<100 THEN
6820               Xscale=INT(Xscale+1)
6830            ELSE
6840               IF Xscale<1000 THEN
6850                  Xscale=10*INT((Xscale+1)/10)
6860               ELSE
6870                  Xscale=100*INT((Xscale+1)/100)
6880               END IF
6890            END IF
6900         END IF
6910      END IF
6920   END IF
6930   GOSUB X_grad
6940   GOSUB Re_plot
6950   RETURN
6960  !
6970  ! ***********************************************************************
6980  ! X SCALE DECREASE
6990  ! ***********************************************************************
7000 Xscaledec:!
7010   IF Xscale<.1 THEN
7020      Xscale=INT((Xscale-.001)*1000)/1000
7030   ELSE
7040      IF Xscale<1 THEN
7050         Xscale=INT((Xscale-.01)*100)/100
7060      ELSE
7070         IF Xscale<10 THEN
7080            Xscale=INT((Xscale-.1)*10)/10
7090         ELSE
7100            IF Xscale<100 THEN
7110               Xscale=INT(Xscale-1)
7120            ELSE
7130               IF Xscale<1000 THEN
7140                  Xscale=10*INT((Xscale-1)/10)
7150               ELSE
```

```
7160                  Xscale=100*INT((Xscale-1)/100)
7170               END IF
7180            END IF
7190         END IF
7200      END IF
7210   END IF
7220   GOSUB X_grad
7230   GOSUB Re_plot
7240   RETURN
7250 !
7260 ! ******************************************************************
7270 ! X MINIMUM DECREASE
7280 ! ******************************************************************
7290 Xmindec:!
7300   IF Xscale<.1 THEN
7310      Xmin=INT((Xmin-.001)*1000)/1000
7320   ELSE
7330      IF Xscale<1 THEN
7340         Xmin=INT((Xmin-.01)*100)/100
7350      ELSE
7360         IF Xscale<10 THEN
7370            Xmin=INT((Xmin-.1)*10)/10
7380         ELSE
7390            IF Xscale<100 THEN
7400               Xmin=INT(Xmin-1)
7410            ELSE
7420               IF Xscale<1000 THEN
7430                  Xmin=10*INT((Xmin-1)/10)
7440               ELSE
7450                  Xmin=100*INT((Xmin-1)/100)
7460               END IF
7470            END IF
7480         END IF
7490      END IF
7500   END IF
7510   GOSUB X_grad
7520   GOSUB Re_plot
7530   RETURN
7540 !
7550 ! ******************************************************************
7560 ! X MINIMUM INCREASE
7570 ! ******************************************************************
7580 Xmininc:!
7590   IF Xscale<.1 THEN
7600      Xmin=INT((Xmin+.001)*1000)/1000
7610   ELSE
7620      IF Xscale<1 THEN
7630         Xmin=INT((Xmin+.01)*100)/100
7640      ELSE
7650         IF Xscale<10 THEN
7660            Xmin=INT((Xmin+.1)*10)/10
7670         ELSE
7680            IF Xscale<100 THEN
7690               Xmin=INT(Xmin+1)
7700            ELSE
7710               IF Xscale<1000 THEN
7720                  Xmin=10*INT((Xmin+1)/10)
7730               ELSE
7740                  Xmin=100*INT((Xmin+1)/100)
7750               END IF
7760            END IF
7770         END IF
7780      END IF
```

```
7790    END IF
7800    GOSUB X_grad
7810    GOSUB Re_plot
7820    RETURN
7830   !
7840   ! *******************************************************************
7850   ! Y SCALE INCREASE
7860   ! *******************************************************************
7870 Yscaleinc:!
7880    IF Yscale<.1 THEN
7890       Yscale=INT((Yscale+.001)*1000)/1000
7900    ELSE
7910       IF Yscale<1 THEN
7920          Yscale=INT((Yscale+.01)*100)/100
7930       ELSE
7940          IF Yscale<10 THEN
7950             Yscale=INT((Yscale+.1)*10)/10
7960          ELSE
7970             IF Yscale<100 THEN
7980                Yscale=INT(Yscale+1)
7990             ELSE
8000                IF Yscale<1000 THEN
8010                   Yscale=10*INT((Yscale+1)/10)
8020                ELSE
8030                   Yscale=100*INT((Yscale+1)/100)
8040                END IF
8050             END IF
8060          END IF
8070       END IF
8080    END IF
8090    GOSUB Y_grad
8100    GOSUB Re_plot
8110    RETURN
8120   !
8130   ! *******************************************************************
8140   ! Y SCALE DECREASE
8150   ! *******************************************************************
8160 Yscaledec:!
8170    IF Yscale<.1 THEN
8180       Yscale=INT((Yscale-.001)*1000)/1000
8190    ELSE
8200       IF Yscale<1 THEN
8210          Yscale=INT((Yscale-.01)*100)/100
8220       ELSE
8230          IF Yscale<10 THEN
8240             Yscale=INT((Yscale-.1)*10)/10
8250          ELSE
8260             IF Yscale<100 THEN
8270                Yscale=INT(Yscale-1)
8280             ELSE
8290                IF Yscale<1000 THEN
8300                   Yscale=10*INT((Yscale-1)/10)
8310                ELSE
8320                   Yscale=100*INT((Yscale-1)/100)
8330                END IF
8340             END IF
8350          END IF
8360       END IF
8370    END IF
8380    GOSUB Y_grad
8390    GOSUB Re_plot
8400    RETURN
8410   !
8420   ! *******************************************************************
8430   ! Y MINIMUM DECREASE
8440   ! *******************************************************************
```

```
8450 Ymindec:!
8460   IF Yscale<.1 THEN
8470      Ymin=INT((Ymin-.001)*1000)/1000
8480   ELSE
8490      IF Yscale<1 THEN
8500         Ymin=INT((Ymin-.01)*100)/100
8510      ELSE
8520         IF Yscale<10 THEN
8530            Ymin=INT((Ymin-.1)*10)/10
8540         ELSE
8550            IF Yscale<100 THEN
8560               Ymin=INT(Ymin-1)
8570            ELSE
8580               IF Yscale<1000 THEN
8590                  Ymin=10*INT((Ymin-1)/10)
8600               ELSE
8610                  Ymin=100*INT((Ymin-1)/100)
8620               END IF
8630            END IF
8640         END IF
8650      END IF
8660   END IF
8670   GOSUB Y_grad
8680   GOSUB Re_plot
8690   RETURN
8700   !
8710   ! ****************************************************************
8720   ! Y MINIMUM INCREASE
8730   ! ****************************************************************
8740 Yminine:!
8750   IF Yscale<.1 THEN
8760      Ymin=INT((Ymin+.001)*1000)/1000
8770   ELSE
8780      IF Yscale<1 THEN
8790         Ymin=INT((Ymin+.01)*100)/100
8800      ELSE
8810         IF Yscale<10 THEN
8820            Ymin=INT((Ymin+.1)*10)/10
8830         ELSE
8840            IF Yscale<100 THEN
8850               Ymin=INT(Ymin+1)
8860            ELSE
8870               IF Yscale<1000 THEN
8880                  Ymin=10*INT((Ymin+1)/10)
8890               ELSE
8900                  Ymin=100*INT((Ymin+1)/100)
8910               END IF
8920            END IF
8930         END IF
8940      END IF
8950   END IF
8960   GOSUB Y_grad
8970   GOSUB Re_plot
8980   RETURN
8990   !
9000   ! ****************************************************************
9010   ! POINTS LINE
9020   ! ****************************************************************
9030 Points_line: !DETERMINES IF POINTS ARE TO BE PLOTTED OR JOINED WITH LINES
9040   IF Point_plot THEN
9050      Point_plot=0
9060      DISP I$;"POINTS WILL BE JOINED BY STRAIT LINES";N$
9070   ELSE
9080      Point_plot=1
9090      DISP I$;"POINTS WILL BE PLOTTED AS '+'";N$
9100   END IF
```

```
9110   RETURN
9120  !
9130  ! ************************************************************
9140  ! PLOT
9150  ! ************************************************************
9160 Plot:  !
9170   DISP I$;"Xmin = ";Xmin;"    Xscale = ";Xscale;" RE-ENTER OR Cont";N$;
9180   INPUT Xmin,Xscale
9190   DISP I$;"Ymin = ";Ymin;"    Yscale = ";Yscale;" RE-ENTER OR Cont";N$;
9200   INPUT Ymin,Yscale
9210   DISP ""
9220   GOSUB X_grad
9230   GOSUB Y_grad
9240 Re_plot:GCLEAR
9250   DEG
9260   GINIT
9270   CLIP ON
9280   VIEWPORT 15,130,13,90
9290   GRAPHICS ON
9300   FRAME
9310   Xmax=Xmin+Xscale
9320   Ymax=Ymin+Yscale
9330   WINDOW Xmin,Xmax,Ymin,Ymax
9340   !
9350   AXES X_tick,Y_tick,Xmin,Ymin,X_major,Y_major,3
9360   DISABLE
9370   LINE TYPE 3
9380   ENABLE
9390  !
9400   MOVE Xmin,0                                   ! DRAWS LINES AT  0,0
9410   DRAW Xmax,0
9420   MOVE 0,Ymin
9430   DRAW 0,Ymax
9440  !
9450   LINE TYPE 1
9460   LDIR 0                                        ! LABLES X-AXIS
9470   LORG 6
9480   CLIP OFF
9490   CSIZE 3.5
9500   MOVE .5*(Xmax+Xmin),Ymin-.05*Yscale
9510   LABEL USING "K";Name1$(X_col);" ";Name2$(X_col);" ";Units$(X_col)
9520  !
9530   CSIZE 2.5                                      ! NUMBERS X-AXIS
9540   LORG 8
9550   Label_increment=X_tick*X_major*2
9560   IF Xscale<=1000 THEN Label_increment=X_tick*X_major
9570   FOR New_counter=Xmin TO Xmax STEP Label_increment
9580      IF ABS(New_counter)<.00001 THEN New_counter=0
9590      New_counter$[1,5]=VAL$(New_counter)
9600      IF POS(New_counter$,".")=0 THEN
9610         Start_pos=6-LEN(VAL$(INT(New_counter)))
9620      ELSE
9630         IF POS(New_counter$,".")=LEN(VAL$(New_counter))-1 THEN
9640            Start_pos=5-POS(New_counter$,".")
9650         ELSE
9660            Start_pos=4-POS(New_counter$,".")
9670         END IF
9680      END IF
9690      Start_pos=MAX(1,Start_pos)
9700      New_counter$[1,5]="     "
9710      New_counter$[Start_pos,5]=VAL$(New_counter)
9720      MOVE New_counter,Ymin-.03*Yscale
9730      LABEL New_counter$
9740   NEXT New_counter
9750   !
9760   Label_increment=Y_tick*Y_major*2                    ! NUMBERS Y AXIS
```

```
9770  IF Yscale<=1000 THEN Label_increment=Y_tick*Y_major
9780  FOR New_counter=Ymin TO Ymax STEP Label_increment
9790     IF ABS(New_counter)<.0001 THEN New_counter=0
9800     New_counter$[1,5]=VAL$(New_counter)
9810     IF POS(New_counter$,".")=0 THEN
9820        Start_pos=6-LEN(VAL$(INT(New_counter)))
9830     ELSE
9840        IF POS(New_counter$,".")=LEN(VAL$(New_counter))-1 THEN
9850           Start_pos=5-POS(New_counter$,".")
9860        ELSE
9870           Start_pos=4-POS(New_counter$,".")
9880        END IF
9890     END IF
9900     Start_pos=MAX(1,Start_pos)
9910     New_counter$[1,5]="     "
9920     New_counter$[Start_pos,5]=VAL$(New_counter)
9930     MOVE Xmin-.005*Xscale,New_counter
9940     LABEL New_counter$
9950  NEXT New_counter
9960 !
9970  LDIR 90
9980  LORG 4
9990  CSIZE 3.5
10000 MOVE Xmin-.07*Xscale,.5*(Ymax+Ymin)
10010 LABEL USING "K";Name1$(Y_col);" ";Name2$(Y_col);" ";Units$(Y_col)
10020 !
10030 LDIR 0                                                ! TITLES GRAPH
10040 LORG 6
10050 MOVE .5*(Xmax+Xmin),Ymax+.10*Yscale
10060 LABEL USING "K";Title$
10070 !
10080 MOVE .5*(Xmax+Xmin),Ymax+.05*Yscale                   ! FRICTION MESSAGE
10090 LABEL USING "K";Message$;",";Data_message$
10100 !
10110 LORG 5                                                ! PLOTS POINTS
10120 WHILE Use_data(First)=0
10130    First=First+1
10140 END WHILE
10150 MOVE Table(First,X_col),Table(First,Y_col)
10160 CSIZE 2.0
10170 IF Point_plot THEN LABEL USING "K";"+"
10180 FOR I=First+1 TO Last
10190    IF Use_data(I)=1 THEN
10200       IF Point_plot THEN
10210          MOVE Table(I,X_col),Table(I,Y_col)
10220          LABEL USING "K";"+"
10230       ELSE
10240          DRAW Table(I,X_col),Table(I,Y_col)
10250       END IF
10260    END IF
10270 NEXT I
10280 !
10290 Position=First
10300 WHILE Use_data(Position)=0
10310    Position=Position+1
10320 END WHILE
10330 Add_times=0
10340 PEN 1
10350 GOSUB Mod_least_sq
10360 CSIZE 3.5
10370 !
10380 RETURN
10390 !
10400 ! ****************************************************************
10410 ! X_GRAD DETERMINES SCALE LABLES FOR X AXIS
10420 ! ****************************************************************
```

```
10430 X_grad:!
10440  IF Xscale<=.5 THEN
10450     X_tick=.01
10460     X_major=5
10470  ELSE
10480     IF Xscale<=1 THEN
10490        X_tick=.02
10500        X_major=5
10510     ELSE
10520        IF Xscale<=5 THEN
10530           X_tick=.25
10540           X_major=4
10550        ELSE
10560           IF Xscale<=10 THEN
10570              X_tick=.5
10580              X_major=4
10590           ELSE
10600              IF Xscale<=50 THEN
10610                 X_tick=2.5
10620                 X_major=4
10630              ELSE
10640                 IF Xscale<=100 THEN
10650                    X_tick=5
10660                    X_major=4
10670                 ELSE
10680                    IF Xscale<=500 THEN
10690                       X_tick=50
10700                       X_major=4
10710                    ELSE
10720                       IF Xscale<=1000 THEN
10730                          X_tick=25
10740                          X_major=4
10750                       ELSE
10760                          X_tick=100
10770                          X_major=5
10780                       END IF
10790                    END IF
10800                 END IF
10810              END IF
10820           END IF
10830        END IF
10840     END IF
10850  END IF
10860  RETURN
10870  !
10880 ! ***********************************************************************
10890 ! Y_GRAD DETERMINES SCALE LABLES FOR Y AXIS
10900 ! ***********************************************************************
10910 Y_grad:!
10920  IF Yscale<=.5 THEN
10930     Y_tick=.01
10940     Y_major=5
10950  ELSE
10960     IF Yscale<=1 THEN
10970        Y_tick=.02
10980        Y_major=5
10990     ELSE
11000        IF Yscale<=5 THEN
11010           Y_tick=.25
11020           Y_major=4
11030        ELSE
11040           IF Yscale<=10 THEN
11050              Y_tick=.5
11060              Y_major=4
11070           ELSE
11080              IF Yscale<=50 THEN
```

```
11090                 Y_tick=2.5
11100                 Y_major=4
11110              ELSE
11120                 IF Yscale<=100 THEN
11130                    Y_tick=5
11140                    Y_major=4
11150                 ELSE
11160                    IF Yscale<=500 THEN
11170                       Y_tick=50
11180                       Y_major=4
11190                    ELSE
11200                       IF Yscale<=1000 THEN
11210                          Y_tick=25
11220                          Y_major=4
11230                       ELSE
11240                          Y_tick=100
11250                          Y_major=5
11260                       END IF
11270                    END IF
11280                 END IF
11290              END IF
11300           END IF
11310        END IF
11320     END IF
11330  END IF
11340  RETURN
11350  !
11360 ! **********************************************************************
11370 ! MOVE CURSOR
11380 ! **********************************************************************
11390 Move_cursor: !
11400  PEN 0
11410  LORG 5
11420  CSIZE 5
11430  IF Add_times THEN
11440     MOVE Table(Position,X_col),Table(Position,Y_col)
11450     LABEL "+"
11460  END IF
11470  Add_times=1
11480  Position_change=INT(KNOBX)
11490  Position=Position+Position_change
11500  IF Position<First THEN Position=Last
11510  IF Position>Last THEN Position=First
11520  WHILE Use_data(Position)=0
11530     Position=Position+SGN(Position_change)
11540     IF Position<First THEN Position=Last
11550     IF Position>Last THEN Position=First
11560  END WHILE
11570  MOVE Table(Position,X_col),Table(Position,Y_col)
11580  LABEL "+"
11590  PEN 1
11600  DISP I$;"POINT ";Position;" : ";Table(Position,X_col);Units$(X_col);" , "
;Table(Position,Y_col);Units$(Y_col);N$
11610  RETURN
11620  !
11630  ! *********************************************************************
11640  ! LOWER LIMIT
11650  ! *********************************************************************
11660 First_point:  !
11670  First=Position
11680  IF First>1 THEN Data_message$="NOT ALL DATA USED"
11690  DISP I$;"LOWER DATA POINT NUMBER =";First;N$
11700  RETURN
11710  !
11720  ! *********************************************************************
11730  ! UPPER LIMIT
```

```
11740  ! *********************************************************************
11750 Last_point:  !
11760  Last=Position
11770  IF Last<Row THEN Data_message$="NOT ALL DATA USED"
11780  DISP I$;"UPPER DATA POINT NUMBER =";Last;N$
11790  RETURN
11800  !
11810  ! *********************************************************************
11820  ! DELETE POINT
11830  ! *********************************************************************
11840 Delete_point:  !
11850  Use_data(Position)=0
11860  Data_message$="NOT ALL DATA USED"
11870  DISP I$;"POINT # ";Position;" DELETED";N$
11880  RETURN
11890  !
11900  ! *********************************************************************
11910  ! ALL POINTS
11920  ! *********************************************************************
11930 All_points:  !
11940  MAT Use_data= (1)
11950  First=1
11960  Last=Row
11970  Data_message$="ALL DATA USED"
11980  DISP I$;Data_message$;N$
11990  RETURN
12000 !
12010 ! ==============================================================
12020 !   LABEL UP
12030 ! ==============================================================
12040 Label_up:   !
12050  LORG 2
12060  LDIR 90
12070  Space1$="-"
12080  Space2$=" "
12090  GOSUB Label_this
12100  LDIR 0
12110  LORG 5
12120  RETURN
12130 !
12140 ! ==============================================================
12150 !   LABEL THIS
12160 ! ==============================================================
12170 Label_this:   !
12180  CSIZE 2.5
12190  MOVE Table(Position,X_col),Table(Position,Y_col)
12200  LABEL USING "A,4A,A,4A,A";Space1$,VAL$(Table(Position,X_col)),",",VAL$(Ta
ble(Position,Y_col)),Space2$
12210  CSIZE 3.5
12220  RETURN
12230 !
12240 ! ==============================================================
12250 !   LABEL DOWN
12260 ! ==============================================================
12270 Label_down:   !
12280  LORG 8
12290  LDIR 90
12300  Space1$=" "
12310  Space2$="-"
12320  GOSUB Label_this
12330  LDIR 0
12340  LORG 5
12350  RETURN
12360    !
12370 !
12380 ! *********************************************************************
```

```
12390 ! PLOT LEAST SQUARE LINE
12400 ! ******************************************************************
12410 Plot_least_sq:   !
12420  GOSUB Mod_least_sq
12430  Line_start=First
12440  Line_end=Last
12450  Temp_val1=Table(First,X_col)
12460  Temp_val2=Table(Last,X_col)
12470  FOR I=First TO Last
12480     IF Use_data(I) THEN
12490        IF Table(I,X_col)<Temp_val1 THEN
12500           Temp_val1=Table(I,X_col)
12510           Line_start=I
12520        END IF
12530        IF Table(I,X_col)>Temp_val2 THEN
12540           Temp_val2=Table(I,X_col)
12550           Line_end=I
12560        END IF
12570     END IF
12580  NEXT I
12590  LINE TYPE 1
12600  PEN 1
12610  CLIP ON
12620  MOVE Table(Line_start,X_col),Table(Line_start,X_col)*Slope+Intercept
12630  DRAW Table(Line_end,X_col),Table(Line_end,X_col)*Slope+Intercept
12640  CLIP OFF
12650  RETURN
12660 !
12670 ! ******************************************************************
12680 ! CHOOSE SECTION
12690 ! ******************************************************************
12700 Choose_section:!
12710  First_1=First
12720  Last_1=Last
12730  First=MIN(First_1,Last_1)
12740  Last=MAX(First_1,Last_1)
12750  IF First=0 OR Last=0 OR Last=First THEN
12760     BEEP
12770     DISP I$;"YOU MUST CHOOSE THE LIMITS AGAIN";N$
12780  END IF
12790  RETURN
12800     !
12810 ! ******************************************************************
12820 ! MODIFIED LEAST SQUARE FIT
12830 ! ******************************************************************
12840 Mod_least_sq: ! FINDS BEST LINE THROUGH CHOOSEN POINTS
12850  Sumx=0
12860  Sumy=0
12870  Sumxy=0
12880  Sumxsq=0
12890  GOSUB Choose_section
12900  Points_used=0
12910  FOR I=First TO Last
12920     IF Use_data(I)=1 THEN
12930       Xpoint=Table(I,X_col)
12940       Ypoint=Table(I,Y_col)
12950       Points_used=Points_used+1
12960       Sumx=Sumx+Xpoint
12970       Sumxsq=Sumxsq+Xpoint*Xpoint
12980       Sumy=Sumy+Ypoint
12990       Sumxy=Sumxy+Xpoint*Ypoint
13000    END IF
13010  NEXT I
13020  Delta=Points_used*Sumxsq-Sumx*Sumx
13030  Slope=(Points_used*Sumxy-Sumx*Sumy)/Delta
13040  Intercept=(Sumy*Sumxsq-Sumx*Sumxy)/Delta
```

```
13050  IF Points_used=Row THEN
13060      DISP I$;"FOR ALL DATA POINTS Y = ";Slope;" *X +";Intercept;N$
13070  ELSE
13080      DISP I$;"FOR SUB SET DATA Y = ";Slope;" *X +";Intercept;N$
13090  END IF
13100  RETURN
13110  !
13120 !
13130 ! ==========================================================
13140 !    DUMP GRAPHICAL OUTPUT TO PRINTER
13150 ! ==========================================================
13160 Dump_graphics:    !
13170  DUMP DEVICE IS 701
13180  DUMP GRAPHICS
13190  Hard_copy=1
13200  PRINTER IS 701
13210  GOSUB Condition_print
13220  PRINT CHR$(12)
13230  PRINTER IS 1
13240  Hard_copy=0
13250  RETURN
13260  !
13270 ! ==========================================================
13280 ! PRINT CONDITIONAL DATA
13290 ! ==========================================================
13300 Condition_print:!
13310  IF UPC$(Data_message$[1,3])="ALL" THEN
13320     PRINT TAB(20);Data_message$
13330     PRINT
13340     PRINT "ALL DATA Y = ";Slope;" *X +";Intercept
13350  ELSE
13360     PRINT Data_message$
13370     PRINT
13380     PRINT TAB(20);"DATA POINT NUMBERS USED"
13390     PRINT
13400     FOR I=First TO Last
13410        IF Use_data(I)=1 THEN PRINT I;",";
13420     NEXT I
13430     PRINT
13440     PRINT
13450     PRINT "FOR SUB SET DATA Y = ";Slope;" *X +";Intercept
13460  END IF
13470  RETURN
13480 !
13490 ! ****************************************************************
13500 ! LIST DATA
13510 ! ****************************************************************
13520 List_data: !
13530  IF NOT Hard_copy THEN GRAPHICS OFF
13540  OFF KEY
13550  ON KEY 1 LABEL " " GOSUB Idle
13560  ON KEY 2 LABEL " " GOSUB Idle
13570  ON KEY 3 LABEL " " GOSUB Idle
13580  ON KEY 4 LABEL " " GOSUB Idle
13590  ON KEY 5 LABEL "RE-START",3 GOTO List_start
13600  ON KEY 6 LABEL " " GOSUB Idle
13610  ON KEY 7 LABEL "CONT.PRINT" GOTO Cont_print
13620  ON KEY 8 LABEL " " GOSUB Idle
13630  ON KEY 9 LABEL "EXIT",3 GOTO List_stop
13640  Start_line=1
13650  !
13660 ! ****************************************************************
13670 ! LIST START
13680 ! ****************************************************************
13690 List_start:  !
13700  GOSUB Hardcopy
```

```
13710  IF NOT Hard_copy THEN PRINT CHR$(12)
13720 !
13730  Page=1
13740  Form=0
13750  L_page=0
13760  Page_end=0
13770 Page_type:        !
13780  Form=Form+1
13790  Page_end=MIN(Form*8,Col)
13800  Page_start=(Form-1)*8+1
13810  GOSUB Form
13820  IF Col<=Page_end THEN List_stop
13830  GOTO Page_type
13840 !
13850 ! ****************************************************************
13860 ! PRINT HEADER
13870 ! ****************************************************************
13880 Print_header: !
13890  PRINT Lin$,Lin$,Lin$
13900  PRINT TAB(20);Title$
13910  IF Message$<>"" THEN
13920     PRINT Message$
13930     PRINT
13940  END IF
13950  RETURN
13960 !
13970 ! ========================================================
13980 !    FORM
13990 ! ========================================================
14000 Form:!
14010  IF Hard_copy THEN
14020     Pages=INT((Row-1)/50)+1
14030  ELSE
14040     Pages=INT((Row-1)/10)+1
14050  END IF
14060  !
14070  FOR L_page=1 TO Pages
14080     GOSUB Print_header
14090     PRINT Lin$
14100     K=0
14110     FOR I=Page_start TO Page_end
14120        K=K+1
14130        PRINT TAB(K*10-9);Name1$(I);
14140     NEXT I
14150     PRINT Lin$
14160     K=0
14170     FOR I=Page_start TO Page_end
14180        K=K+1
14190        PRINT TAB(K*10-9);Name2$(I);
14200     NEXT I
14210     K=0
14220     PRINT Lin$
14230     FOR I=Page_start TO Page_end
14240        K=K+1
14250        PRINT TAB(K*10-9);Units$(I);
14260     NEXT I
14270     PRINT Lin$
14280     PRINT
14290     IF Hard_copy THEN
14300        FOR I=L_page*50-49 TO L_page*50
14310           IF I>Row THEN End_form_1
14320           K=0
14330           FOR J=Page_start TO Page_end
14340              K=K+1
14350              PRINT TAB(K*10-9);
14360              IF Table(I,J)=-1.E+6 THEN
```

```
14370                   PRINT "  N/A  ";
14380                ELSE
14390                   IF ABS(Table(I,J))<1000 AND ABS(Table(I,J))>.01 OR ABS(Tab
le(I,J))<1.E-6 THEN
14400                      PRINT USING "MDDD.DDD,#";Table(I,J)
14410                   ELSE
14420                      PRINT USING "MD.DDE,#";Table(I,J)
14430                   END IF
14440                END IF
14450             NEXT J
14460             PRINT
14470          NEXT I
14480       ELSE
14490          FOR I=L_page*10-9 TO L_page*10
14500             IF I>Row THEN End_form_1
14510             K=0
14520             FOR J=Page_start TO Page_end
14530                K=K+1
14540                PRINT TAB(K*10-9);
14550                IF Table(I,J)=-1.E+6 THEN
14560                   PRINT "  N/A  ";
14570                ELSE
14580                   IF ABS(Table(I,J))<1000 AND ABS(Table(I,J))>.01 OR ABS(Tab
le(I,J))<1.E-6 THEN
14590                      PRINT USING "MDDD.DDD,#";Table(I,J)
14600                   ELSE
14610                      PRINT USING "MD.DDE,#";Table(I,J)
14620                   END IF
14630                END IF
14640             NEXT J
14650             PRINT
14660          NEXT I
14670       END IF
14680 End_form_1:        !
14690       IF NOT Hard_copy THEN
14700          DISP "PUSH ";I$;" CONT.PRINT ";N$;" WHEN READY"
14710 Here:  GOTO Here
14720 Cont_print:DISP ""
14730       END IF
14740       PRINT CHR$(12)
14750  NEXT L_page
14760  RETURN
14770   !
14780 ! **************************************************************************
14790 ! LIST STOP
14800 ! **************************************************************************
14810 List_stop:!
14820  IF NOT Hard_copy THEN PRINT CHR$(12)
14830  PRINTER IS 1
14840  Hard_copy=0
14850  DISP I$;"PICK A KEY ... ANY KEY ... EVERYONE IS A WINNER";N$
14860  OFF KEY
14870  GRAPHICS ON
14880  GOTO Graphics_keys
14890        !
14900 ! **************************************************************************
14910 ! THE_END
14920 ! **************************************************************************
14930 The_end: !
14940  DISP I$;"THAT'S ALL FOR NOW";N$
14950  END
```

APPENDIX B

CATALOGUE OF 343 EVENTS

SOURCE: CANMAR

EVENT #	TYPE	INTER-UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
1	0	-	-	-	06-19	18:07:15	Only CH.1-7 Recorded, Sliding Block Full Bridge, Offset - 300LSB, 4000 Points
2	-	-	-	-	-	-	No Disk CH.7 Polarity. Reversed Tests #2-17
3	0	-	-	-	06-20	00:07:36	Only Channels 1-7 Recorded, 4000 Points
4	B	-	I	F	06-20	13:28:32	Only Channels 1-7 Recorded, 4000 Points
5	S	-	I	F	06-20	13:39:35	Only Channels 1-7 good; 4000 Points, most Neg. Sliding Block Force
6	M	-	I	F	06-20	20:55:51	Ch. 13 is probe; Ch. 11-14, probes not connected
7	S	-	I	F	06-21	20:27:49	Outbound McKinley Channel; Ch. 6,7,11,12,13,14, 17 NFG
8	S	-	I	F	06-21	20:33:01	Ch. 7,14,15,17, NFG, Fifth Largest Blade Force
9	M	-	I	F	06-21	20:49:48	Ch. 7,14,15,17,NFG, 6999 Data Points
10	S	0	-	F	06-21	23:14:18	McKinley Channel, Inbound; Ch. 7,14,15,17 NFG
11	S	0	-	F	06-21	23:35:38	Ch. 7, 14, 15, 17 NFG
12	S	0	-	F	06-21	23:42:09	McKinley Basin, Ch. 7,14,15,17 NFG, 6999 Data Points
13	0	0	0	0	06-30	01:41:44	Zero Pitch, Engine Idle, Ch. 7,11,13,14 NFG, S.B. becomes 1/2 bridge
14	0	0	0	F	06-30	02:20:14	Creeping Ahead Ch. 13 Becomes Fuelrack
15	0	0	0	F	06-30	02:46:23	Slow Ahead, Ch. 7 Zero Offset Tests #13 - 58
16	0	0	0	F	06-30	03:10:25	Half Ahead
17	0	0	0	F	06-30	03:29:26	Full Ahead
18	0	0	0	R	06-30	03:43:49	Half Astern, Rudder Over
19	0	0	0	F	06-30	08:46:10	Ahead
20	0	0	0	F	06-30	09:53:45	Ahead, 6724 Data Points
21	0	0	0	F	06-30	21:54:23	Half Ahead
22	0	0	0	F	06-30	22:32:33	Full Ahead, 6973 Data Points
23	0	0	I	F	06-30	22:37:08	Full Ahead Deteriorated Ice
24	S	1	I	F	06-30	22:40:58	Rotten Ice 0.5m Freeboard
25	S	1	I	F	06-30	22:41:27	Rotten Ice 0.5m Freeboard
26	S	1	I	F	06-30	22:42:29	Rotten Ice 0.5m Freeboard
27	0	0	I	F	06-30	23:16:37	STBD Shaft Stopped, Loose Ice

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: CATALOGUE OF 343 EVENTS APPENDIX B

EVENT #	TYPE	INTER-UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
28	O	64	O	F	07-01	00:51:55	Full Power
29	S	136	I	F	07-01	01:00:18	Rotten Ice 1.5m
30	O	128	I	F	07-01	01:00:51	
31	S	72	I	F	07-01	01:01:52	
32	S	72	I	F	07-01	01:02:36	
33	S	128	I	F	07-01	01:03:14	Short Event Duration, 6714 Points
34	S	136	I	F	07-01	01:03:58	
35	S	128	I	F	07-01	01:04:29	6447 Data Points
36	S	128	I	F	07-01	01:05:02	
37	S	8	I	F	07-01	01:05:31	
38	S	128	I	F	07-01	01:06:36	Short Event Duration
39	S	16	I	F	07-01	01:07:06	
40	S	4	I	F	07-01	01:07:47	
41	S	64	I	F	07-01	01:06:04	
42	M	4	I	F	07-01	01:08:14	
43	M	64	I	F	07-01	01:09:09	
44	O	2	I	F	07-01	01:09:38	Ch. 2 Glitch From Points 2260 to 2277, Fixed In Software
45	B	56	I	F	07-0-1	01:10:38	
46	B,S	50	I	F	07-01	01:11:07	Second Most Neg. Sliding Block Force
47	B,S	8	I	F	07-01	01:12:06	
48	S	4	I	F	07-01	01:13:42	
49	M	16	I	F	07-01	01:14:10	6th Largest Spindle Torque
50	M	1	I	F	07-01	01:21:47	
51	B	1	I	F	07-01	01:22:18	Tape Read Data Error, 3920 Points
52	M	4	I	F	07-01	01:30:54	
53	B	4	I	F	07-01	01:31:31	Alot of Blockage Ch. 7 Glitch @ Points 1131, Fixed In Software
54	S	4	I	F	07-01	01:32:12	2nd Larger Sliding Block Force, 3rd Largest Spindle Torque

EVENT #	TYPE	INTER-UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
55	S	144	I	F	07-01	01:33:47	Ch. #2 Glitch Points 5513 to 5537, Fixed
56	-	-	-	-	-	-	Blank Disk
57	0	4	I	F	07-01	01:35:55	Tape Read Data Error, 6538 Points
58	M,B	1	I	F	07-01	01:36:24	Good Hits, Ch. 7 Glitch, Software Fix
59	0	4	I	F	07-01	01:41:20	6575 Data Points
60	M	73	I	F	07-01	01:41:48	Ch. 7 NFG For Tests 59-116
61	M	256	I	F	07-01	01:42:34	
62	B,S	256	I	F	07-01	01:43:07	Start & End Impacts, 6708 Data Points
63	S	4	I	F	07-01	01:47:14	
64	0	4	I	F	07-01	01:48:43	
65	B	65	I	F	07-01	01:53:05	
66	M	16	I	F	07-01	01:55:01	6577 Data Points
67	M	26	I	F	07-01	01:55:45	6870 Data Points
68	M	25	I	F	07-01	01:56:12	First Year Ridge 0.5 m Sail Tests #68 to 72
69	M	18	I	F	07-01	01:57:29	Glitches In data, Fixed In Software
70	S	256	I	F	07-01	01:58:00	
71	M	256	I	F	07-01	01:58:42	
72	M	88	I	F	07-01	02:06:36	First Year Ridge 4m Pieces, Largest Blade Force
73	S	144	I	F	07-01	02:10:35	Wrong Test #, On Disk - 103
74	B	24	I	F	07-01	02:15:16	
75	S	24	I	F	07-01	02:16:01	
76	S	2	I	F	07-01	02:16:52	6450 Data Points
77	S	136	I	F	07-01	02:22:49	
78	B	9	I	F	07-01	02:23:41	
79	B	128	I	F	07-01	02:24:29	
80	B	4	I	F	07-01	02:24:58	
81	M	73	I	F	07-01	02:25:38	

EVENT #	TYPE	INTER-UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
82	B	24	I	F	07-01	02:26:18	
83	M	128	I	F	07-01	02:31:16	1st Year Ridge, 2m Sail, Most Neg. Spindle Torque
84	B,S	128	I	F	07-01	02:35:19	6574 Data Points
85	S	201	I	F	07-01	02:37:05	Hard Impacts, 6575 Data Points
86	S	136	I	F	07-01	02:42:37	
87	S	136	I	F	07-01	02:44:24	
88	S	136	I	F	07-01	02:45:29	Shaft Thrust Ch. 8, NFG. Tests 84-88
89	S	128	I	F	07-01	02:47:38	Good Single Hit
90	S	73	I	F	07-01	02:48:43	
91	M	72	I	F	07-01	02:52:29	Shaft Thrust Ch. 8 NFG
92	S	136	I	F	07-01	02:58:24	Glitch @ Points 2185 Ch. 16, Software Fix
93	M	64	I	F	07-01	03:05:56	2m Ice Pan Melted Ridges, Ch. 8 NFG
94	S	4	I	F	07-01	03:14:04	
95	M	4	I	F	07-01	03:14:36	Milling Started During Event
96	S	4	I	F	07-01	03:15:40	
97	B,S	61	I	F	07-01	03:17:16	6726 Data Points
98	B,S	64	I	F	07-01	03:20:28	
99	S	128	I	F	07-01	03:23:03	5765 Data Points
100	S	73	I	F	07-01	03:24:03	
101	S	73	I	F	07-01	03:30:03	
102	M	1	I	R	07-01	03:36:52	Most Neg. Blade Force, Most Neg. Bending Moment Largest Thrust
103	M	0	I	R	07-01	03:41:26	Test # is 102, 3rd Most Neg. Blade Force, 2nd Largest Thrust
104	O	1	I	F	07-01	03:53:32	
105	B,S	65	I	F	07-01	03:55:28	Second Most Neg. Blade Force
106	M	65	I	F	07-01	04:02:21	
107	M	65	I	F	07-01	04:05:02	Good Event, Half Slow Ahead
108	B	64	I	F	07-01	04:07:24	Slow Ahead

EVENT #	TYPE	INTER-UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
109	B,S	64	I	F	07-01	04:09:08	
110	S	128	I	F	07-01	04:10:37	6723 Data Points
111	B	160	I	F	07-01	04:11:46	
112	B	64	I	F	07-01	04:12:55	Ch. 12 NFG For Test # 114 Only
113	B	64	I	F	07-01	04:13:32	6982 Data Points
114	0	0	0	F	07-01	18:28:30	Ch. 7, 1/4 Bridge Test, 6644 Data Points
115	0	0	I	F	07-02	14:39:57	Shaft Movement Due To Hull Girder Vibration.
116	0	0	I	F	07-02	17:45:41	Shaft Movement Due to Hull Girder Vibration 6433 Points
117	S,B	64	I	F	07-02	17:48:31	Largest Shaft Torque, 3rd Most Neg. Shaft Thrust
118	M	65	I	F	07-02	17:49:12	Large Torque & Small Force, 6588 Points
119	S	64	I	F	07-02	17:50:13	6450 Data Points
120	B,S	64	I	F	07-02	17:51:23	Tape Read Data Error, 5698 Points
121	S	161	I	F	07-02	18:14:02	Ch. 7 Offset - 51 LSB, Tests #114 - 123, Fixed In Software
122	S	128	I	F	07-02	18:15:19	Running Over 1/2 m First Year Ridge
123	S	1	I	F	07-02	18:19:33	6715 Data Points
124	B,S	65	I	F	07-02	18:20:55	Interesting Time History Of Force
125	B	65	I	F	07-02	19:51:44	Ch. 7 Offset By-110 LSB Tests 124 - 187, Fixed in Software
126	S	65	I	F	07-02	19:53:07	
127	B	64	I	F	07-02	19:53:33	Second Most Neg. Shaft Thrust
128	S	65	I	F	07-02	19:54:52	Fifth Most Neg. Shaft Thrust
129	B,S	64	I	F	07-02	19:55:42	Fourth Most Neg. Shaft Thrust
130	B	64	I	F	07-02	19:56:13	Most Neg. Shaft Thrust
131	M	64	I	F	07-02	19:59:34	
132	B	64	I	F	07-02	20:00:07	
133	M	9	I	F	07-02	20:01:12	6999 Data Points
134	S	9	I	F	07-02	20:01:59	
135	0	0	I	R	07-02	20:06:21	Breaking Astern 6th Largest Shaft Thrust

EVENT #	TYPE	INTER-UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
136	S	0	I	R	07-02	20:07:05	Ship Moving Astern, Ahead Thrust
137	S	9	I	F	07-02	20:08:42	Ahead, Turning to Port, 6866 Points
138	S	32	I	F	07-02	20:10:49	Fifth Largest Shaft Torque
139	B	1	I	F	07-02	20:13:12	
140	B,S	9	I	F	07-02	20:15:39	
141	S	9	I	F	07-02	20:16:11	Third Largest Shaft Torque
142	M	169	I	F	07-02	20:18:50	Crossing First Year Ridge 1-1.5m Sail
143	O	0	I	R	07-02	20:18:31	6708 Points, 3rd Largest Shaft Thrust
144	O	0	I	R	07-02	20:21:13	6869 Broken Channel 4th Largest Thrust
145	O	0	I	R	07-02	20:22:29	Broken Channel, To STBD, 5th Largest Thrust
146	S	1	I	F	07-02	20:27:31	Breaking New Channel Ahead, 6853 Points
147	S	9	I	F	07-02	20:28:53	Glitches in Data, Fixed in Software
148	M	9	I	F	07-03	10:13:54	
149	S	1	I	F	07-03	10:21:11	
150	S	1	I	F	07-03	10:24:06	6850 Data Points
151	S	1	I	F	07-03	10:26:33	
152	S	1	I	F	07-03	10:28:43	
153	B	1	I	F	07-03	10:29:17	
154	B	1	I	F	07-03	10:30:57	
155	B,S	1	I	F	07-03	10:34:58	
156	M	9	I	F	07-03	10:35:27	
157	M	9	I	F	07-03	10:36:00	
158	M	1	I	F	07-03	10:37:20	6844 Data Points
159	B	1	I	F	07-03	10:44:01	Stern Crossing Ridge, 6710 Data Points
160	S	169	I	F	07-03	10:48:38	Crossing First Year Ridge
161	B	1	I	F	07-03	10:49:21	
162	M	1	I	F	07-03	10:54:57	Long Milling Duration

EVENT #	TYPE	INTER- UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
163	S	33	I	F	07-03	11:00:53	High Thrust Low Torque & Vice Versa
164	S	1	I	F	07-03	11:03:19	
165	S	65	I	F	07-03	11:04:06	6723 Points, 2nd Largest Blade Force, 2nd Largest Bending Moment, Largest Spindle Torque
166	S	1	I	F	07-03	11:05:42	Third Largest Pos. Sliding Block Force, 6977 Points
167	S	32	I	F	07-03	11:07:45	Test #Says 168, 6852 Data Points
168	M	33	I	F	07-03	11:08:28	
169	B,S	1	I	F	07-03	11:15:19	Wrong Title On Disk "propdata"
170	S	1	I	F	07-03	11:16:39	6668 Points, 4th Largest Blade Force, 2nd Most Neg. Spindle Torque
171	B	73	I	F	07-03	11:17:31	
172	M	41	I	F	07-03	11:18:18	3 Ch. Trigger, 6998 Data Points
173	M,S	41	I	F	07-03	11:20:25	3 Ch. Trigger, Stern Crossing Ridge
174	S	168	I	F	07-03	12:44:53	
175	S	1	I	F	07-03	12:55:44	
176	S	160	I	F	07-03	12:57:24	
177	M	9	I	F	07-03	12:58:26	Milling Ends During Test
178	M	128	I	F	07-03	13:01:03	Largest Sliding Block Load, 4th Largest Spindle Torque
179	S	1	I	F	07-03	13:04:14	8th Largest Shaft Torque
180	S	9	I	F	07-03	13:04:42	Extremely Fast Impact
181	M	1	I	F	07-03	13:06:04	
182	S	32	I	F	07-03	13:06:50	
183	S	9	I	F	07-03	13:07:24	
184	S	9	I	F	07-03	13:08:56	
185	S	1	I	F	07-03	13:13:48	
186	M	64	I	F	07-03	13:15:41	Second Largest Shaft Torque
187	B	1	I	F	07-03	13:16:10	Blockage Ends During Test
188	S	41	I	F	07-03	13:18:20	6998 Data Points
189	B	1	I	F	07-03	13:19:29	Ch. 7 Offset - 127 LSB Tests 188-209, Fixed In Software

EVENT #	TYPE	INTER-UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
190	S	9	I	F	07-03	13:20:28	Two Hits
191	S	160	I	F	07-03	13:27:31	
192	M	32	I	F	07-03	13:30:43	Milling Ends During Test
193	B	1	I	F	07-03	13:34:36	6564 Data Points
194	B	32	I	F	07-03	13:35:03	
195	S	1	I	F	07-03	13:38:07	
196	B	1	I	F	07-03	13:39:37	
197	M	169	I	F	07-03	13:40:15	Loose Ice Pieces
198	M	41	I	F	07-03	13:42:41	
199	M	1	I	F	07-03	13:43:14	
200	M	9	I	F	07-03	13:53:26	
201	S	32	I	F	07-03	13:55:11	6576 Data Points
202	M	9	I	F	07-03	13:59:27	
203	B	32	I	F	07-03	13:59:59	
204	B	65	I	F	07-03	14:01:58	
205	M,S	169	I	F	07-03	14:06:00	
206	B	1	I	F	07-03	14:06:58	Shaft Thrust,. Ch. 8, Drifts After This Test
207	0	0	I	R	07-03	14:47:21	Astern
208	0	0	I	R	07-03	14:48:08	Astern
209	0	0	I	R	07-03	14:53:00	Ch. 7 Offset - 165 LSB, Test 210 - 343, Fixed in Software
210	0	0	0	F	07-03	15:05:44	Turn To Port Open Water
211	0	0	0	F	07-03	15:06:15	Turn To Port, Open Water
212	0	0	0	F	07-03	15:11:15	Turn To STBD, Open Water
213	0	0	0	F	07-03	15:11:48	Turn To STBD, Open Water
214	S	1	I	F	07-03	16:48:13	
215	S	9	I	F	07-03	17:30:56	
216	S	9	I	F	07-03	17:31:31	

EVENT #	TYPE	INTER-UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
217	R	1	I	F	07-03	17:36:11	Ridge Stopped Ship, 6999 Points
218	B	32	I	F	07-03	17:36:37	Ridge Stopped Ship
219	B,S	32	I	F	07-03	17:37:59	Blockage, Then Impact, 6705 Points
220	B,S	1	I	F	07-03	17:38:31	
221	S	32	I	F	07-03	17:41:16	
222	S	1	I	F	07-03	17:41:47	6999 Data Points
223	S	73	I	F	07-03	17:42:59	6th Largest Blade Force, 4th Largest Bending Moment
224	M,S	160	I	F	07-03	17:43:33	
225	S	9	I	F	07-03	17:44:09	
226	M	9	I	F	07-03	17:44:39	
227	M,B	1	I	F	07-03	18:43:52	
228	B	1	I	F	07-03	18:45:31	Blockage Ends During Impact
229	M,B	128	I	F	07-03	18:46:18	Free Vibration Of Blade, 6703 Points
230	S	73	I	F	07-03	18:47:38	Seventh largest Shaft Torque
231	M	9	I	F	07-03	18:50:22	
232	S	128	I	F	07-03	18:53:21	6439 Points
233	S	9	I	F	07-03	18:53:58	
234	M,S	73	I	F	07-03	18:54:27	
235	S	65	I	F	07-03	18:55:46	
236	S	168	I	F	07-03	18:56:53	
237	S	73	I	F	07-03	18:59:47	6578 Data Points
238	1	1	I	F	07-03	19:00:24	
239	M,B	64	I	F	07-03	19:01:08	6575 Points, 2nd largest Spindle Torque
240	M	1	I	F	07-03	19:01:48	
241	S	9	I	F	07-03	19:03:13	
242	M	65	I	F	07-03	19:07:02	
243	S	128	I	F	07-03	19:07:57	

EVENT #	TYPE	INTER-UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
244	B,S	64	I	F	07-03	19:08:42	6852 Data Points
245	S	160	I	F	07-03	19:13:46	
246	S	32	I	F	07-03	19:14:38	
247	S	128	I	F	07-03	19:17:15	
248	S	136	I	F	07-03	19:17:56	Single Impact
249	S	73	I	F	07-03	19:18:47	
250	B	1	I	F	07-03	19:14:58	
251	M	128	I	F	07-03	19:20:38	
252	S	168	I	F	07-03	19:21:35	6849 Data Points
253	M	32	I	F	07-03	19:22:23	
254	0	512	I	R	07-03	19:23:53	Thrust Ch. 8 NFG. This Test
255	S	9	I	F	07-03	19:28:49	
256	B,S	9	I	F	07-03	19:29:54	
257	S	32	I	F	07-03	19:30:39	6854 Data Points
258	B	9	I	F	07-03	19:31:29	6824 Data Points
259	S	9	I	F	07-03	19:43:20	
260	S	32	I	F	07-03	19:43:49	
261	S	7	I	F	07-03	19:46:40	
262	B,S	7	I	F	07-03	19:50:02	
263	S	9	I	F	07-03	19:52:56	6432 Data Points
264	S	64	I	F	07-03	19:53:36	Single Impact
265	S	64	I	F	07-03	19:54:20	6435 Data Points
266	S	168	I	F	07-03	19:54:50	
267	S	9	I	F	07-03	19:55:22	
268	S	64	I	F	07-03	19:57:36	
269	S	168	I	F	07-03	19:58:49	
270	0	0	I	0	07-03	20:04:19	Zero Level, STBD. Clutch Kicked Out

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: CATALOGUE OF 343 EVENTS APPENDIX B

EVENT #	TYPE	INTER-UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
271	M	8	I	F	07-03	20:10:17	
272	B,S	32	I	F	07-03	20:11:28	
273	B	65	I	F	07-03	20:12:23	
274	S	64	I	F	07-03	20:17:41	6849 Data Points
275	S	8	I	F	07-03	20:22:45	
276	S	32	I	F	07-03	20:24:07	
277	M	9	I	F	07-03	20:30:08	
278	M	32	I	F	07-03	20:31:16	
279	S	32	I	F	07-03	20:34:08	Single Impact
280	M,S	64	I	F	07-03	20:36:01	Long Event
281	S	8	I	F	07-03	20:38:06	Glitch In Data, 6000 Good Points, Fixed in Software
282	B	32	I	F	07-03	20:38:51	6845 Data Points
283	S	160	I	F	07-03	20:47:50	
284	B	73	I	F	07-03	20:50:40	
285	S	9	I	F	07-03	20:52:22	6437 Points, 6th Largest Bending Moment
286	S	8	I	F	07-03	20:55:23	Single Impact
287	S	160	I	F	07-03	20:57:23	6554 Data Points
288	S	73	I	F	07-03	20:58:13	
289	M	160	I	F	07-03	21:01:27	Free Vibration of Shaft
290	M	73	I	F	07-03	21:04:20	
291	M	40	I	F	07-03	21:05:25	
292	M	32	I	F	07-03	21:08:35	Long Event, 6570 Data Points
293	S	168	I	F	07-03	21:11:07	
294	M	73	I	F	07-03	21:11:35	
295	S	128	I	F	07-03	21:12:09	
296	S	8	I	F	07-03	21:13:27	
297	S	64	I	F	07-03	21:15:26	5th Largest Spindle Torque

EVENT #	TYPE	INTER-UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
298	B	32	I	F	07-03	21:28:08	6559 Data Points
299	M	32	I	F	07-03	21:29:47	Ch. 4 NFG From Here On, 4th Largest Sliding Block Force
300	0	32	I	F	07-03	21:30:18	
301	M	32	I	F	07-03	21:30:46	
302	0	32	I	F	07-03	21:31:27	6981 Data Points
303	0	736	I	F	07-03	21:32:13	
304	S	8	I	F	07-03	21:35:36	
305	S	1	I	F	07-03	21:38:58	6844 Data Points
306	M	136	I	F	07-03	21:41:20	Tape Read Data Error, 5607 Points
307	S	136	I	F	07-03	21:43:58	
308	B	9	I	F	07-03	21:46:27	
309	S	9	I	F	07-03	21:49:40	
310	S	64	I	F	07-03	21:51:07	
311	S	9	I	F	07-03	21:53:14	Short Duration
312	M	137	I	F	07-03	22:04:02	
313	M	137	I	F	07-03	22:05:01	6987 Points, 4th Largest Shaft Torque, 3rd Largest Bending Moment.
314	S	8	I	F	07-03	22:07:07	3rd Most NEG. Spindle Torque
315	S	136	I	F	07-03	22:10:26	
316	S	73	I	F	07-03	22:13:13	6990 Data Points
317	B,S	8	I	F	07-03	22:14:34	
318	S	64	I	F	07-03	22:17:34	
319	M	9	I	F	07-03	22:21:25	
320	S	73	I	F	07-03	22:22:36	6841 Points, 5th Largest Bending Moment
321	M	9	I	F	07-03	22:25:03	
322	B	9	I	F	07-03	22:25:33	6589 Data Points
323	B,S	9	I	F	07-03	22:27:42	
324	B	64	I	F	07-03	22:28:45	Blockage

EVENT #	TYPE	INTER-UPT DATA	OPEN WATER OR ICE	DIR. OF TRAVEL	DATE RECORD	TIME RECORDED	COMMENTS
325	M	9	I	F	07-03	22:32:08	
326	M	65	I	F	07-03	22:40:05	
327	S	8	I	F	07-03	22:45:52	Short Duration
328	M	64	I	F	07-03	22:46:26	Sixth Largest Shaft Torque
329	S	73	I	F	07-03	22:47:55	Vibration Of Shaft, 5446 Points
330	S	8	I	F	07-03	22:56:53	
331	S	8	I	F	07-03	23:03:04	
332	S	136	I	F	07-03	23:03:35	
333	S	9	I	F	07-03	23:04:23	Long Interaction
334	M	64	I	F	07-03	23:06:56	
335	S	136	I	F	07-03	23:08:15	Single Impact, 6577 Points
336	S	201	I	F	07-03	23:11:16	Third Largest Blade Force, Largest Bending Moment
337	-	137	-	-	07-03	23:12:17	Will Not Pead, Integer Out of Range
338	M	136	I	F	07-03	23:17:26	
339	S	9	I	F	07-03	23:23:28	
340	S	8	I	F	07-03	23:24:42	
341	M	136	I	F	07-03	23:32:02	
342	M,S	9	I	F	07-03	23:34:25	
343	0	32	I	R	07-03	23:44:11	2457 Data Points

APPENDIX C

BLADE STRESS-STRAIN ANALYSIS

SOURCE: CANMAR

BLADE STRESS STRAIN RELATIONSHIP

Background Equations

Although the blade had been calibrated to record the steady state relationships between applied load and the six strain gauges, and an algorithm known as the [A] matrix was developed to allow a prediction of the magnitude, direction and location of a steady load to suit a given set of strain gauge readings, it was still necessary to establish a relationship between gauge strain and stress if stress levels in the blade were to be assessed.

The unidirectional stress/strain relationship is governed by Hooke's Law within the elastic limit of the material i.e.:

$\sigma / \varepsilon = E$ where $\sigma =$ normal stress, $\varepsilon =$ normal strain, E is Young's Modulus

and for shear stress $\tau / \phi = G$ where $\tau =$ shear stress, $\phi =$ shear strain and G is Modulus of Rigidity

The relationship between G and E is given by

$G = \dfrac{E}{2(1 + \nu)}$ where $\nu =$ Poisson's Ratio

When these basic equations are applied to the strain measurements detected by a strain gauge bridge, a stress formula, related to the bridge output voltage, may be establish, viz:

$$\sigma_1 - \sigma_2=(2E/(1-\nu) * (1/k)\ 0\ (V_{out}/V_{in}) * (1/gain) \qquad (1)$$

This formula was produced by VTT (The Technical Research Centre of Finland) who pioneered the concept of a series of six strain gauges for propeller blade stress measurements. Both the material relationship elements, and the electrical bridge configuration aspects of formula (1) were checked independently during the course of this project and were found to be correct. Inserting the values for E and D as given in Table 3.1-1, and using the electrical constants for the bridge configuration, reduced to:

$\sigma_1 - \sigma_2 = 45.1$ MPa/volt

Similarly, a shear stress/bridge output voltage relationship was specified, viz.

$$\tau_1 - \tau_2 = (2E /(1-\nu) * (1/K) * (V_{out}/V_{in})*(1/gain) \qquad (2)$$

Again independent researches checked the validity of this formula. Inserting material and electrical values yields:

$$\tau_1 - \tau_2 = 12.3 \text{ MPa / volt}$$

The combinations of normal stress, σ, and shear stress, τ, results in a principal stress τ_e given by the well-established relationship:

$$\tau_e = (\sigma^2 + 3\tau^2)^{1/2}$$

or

$$\sigma_e / \sigma_1 = (1 + 3 (\tau_1 / \sigma_1)^2)^{1/2}$$

Where it has been assumed that the stresses are pressure and suction sides of the blade are equal and opposite in sign i.e.

$$\sigma_1 = -\sigma_2 \qquad (4)$$

and

$$\tau_1 = -\tau_2 \qquad (5)$$

A further complication is found in the fact that the strain gauges were placed in machined recesses in the blade surface, so that the strains were not actually measured at the location of what would have been the extreme fibers. This inaccuracy is remedied by assuming a linear relationship between stress and the distance to the neutral areas of the blade section. In the subject case, the blade configurations are as given on the following page:

Blade/Gauge Particulars

Radial Location	Blade Width W mm	Max Thickness t_{Max} mm	Distance between Gauges tmm	Stress Ratio σ_e/σ_1
0.47r/R	836	116.7	85.08	73%
0.60r/R	1029	87.7	63.8	73%

From the above ratio calculations it is postulated that the principle stress at the extreme fiber is related to the principle stress level at the location of the gauges by the equation,

$$\sigma_e \text{ (extreme fiber)} = \sigma_e \text{ (strain gauge location)} * 1 / 0.73$$

$$\sigma_e \text{ (ef)} = 1.37\ \sigma_e \text{ (s.g.l.)}$$

The validity of this assumption is dependent upon a lack of any stress concentration at the location of the gauges caused by the altered profile due to the machining operation. In reality a correction factor of unknown value should be applied.

Furthermore, the strain gauge bridge configuration produces a measurement of:

$$\text{normal stress reading} = \sigma_1 - \sigma_2$$
$$\text{and sheer stress reading} = \tau_1 - \tau_2$$

but from equations (4) and (5)

$$\sigma_1 - \sigma_2 = \Delta\sigma = 2\sigma_1$$
$$\text{and} \quad \tau_1 - \tau_2 = \Delta\tau = 2\tau_1$$

$$\text{so that} \quad \sigma_{e(ef)} = 1.37\ (\sigma_1^2 + 3\tau_1^2)^{1/2}$$
$$= 0.685\ ((\Delta\sigma)^2 + 3(\Delta\tau)^2)^{1/2}$$

(7)

If the shear stress measurement, $\Delta\tau$, can be ignored in proportion to the normal stress measurement, $\Delta\sigma$, the equation reduces to:

$$\sigma_e \text{ (e.f.)} = 0.685\ \Delta\sigma$$

APPENDIX D

SOFTWARE PROGRAMS FOR LONG TERM SHAFT STATISTICS ANALYSIS

SOURCE: CANMAR

CONTENTS

HIST13 1

HIST14 14

```
10     REM PROGRAM *HIST*/ VERSION 13/ MHE/KPK 84/11/20
20     REM USES STRUCTURED PROGRAMMING ,CAN ONLY BE USED ON HP9845C
30     REM OTHERWISE IS IDENTICAL TO VERSION 11 USED ON HP9845A
40     REM PROGRAM TO CALCULATE AND PLOT AMPLITUDE-FREQUENCY HISTOGRAMS
50     REM USING DATAMYTE 400 RAINFLOW-COUNTED HISTOGRAMS AS INPUT
60     REM HIST05 PROVIDES SEMI-LOG HISTOGRAM OUTPUT AND SUPRESSES
70     REM THE PLOTTING OF THE FIRST BIN ON EITHER SIDE OF ZERO
80     REM HIST05 INCORPORATES THE OPTION OF PLOTTING AS A FN OF YIELD
90     REM HIST06 INCORPORATES THE OPTION OF EXTRAPOLATING THE LOAD
100    REM HISTORY TO LARGE TIMES USING A LINEAR REGRESSION ON THE LOG
110    REM OF THE TOTAL NUMBER OF COUNTS IN EACH BIN
120    REM HIST07 HAS VARIABLE INPUT DATA FIELD LENGTH AND WILL READ
130    REM DATA FILES WITH OR WITHOUT THE ICE THICKNESS PARAMETER
140    REM
150    REM HIST09 HAS BEEN MODIFIED FOR ANALYSING SHAFT TORQUE VARIATION.
160    REM *HIST11* IS FOR TORQUE ANL THRUST WAVEFORMS
170    REM ONLY VERSIONS HIST11 AND HIST12 HANDLE ODD NUMBERED RANGES
180    REM PROPERLY
190   !
200    OPTION BASE 1
210    INTEGER I,J,K,N,Lines,Hys,Bias,Dm
220    DIM Bin(32),R(300),M(300),N(300)
230    DIM Name$[30]
240    MAT R=ZER
250    MASS STORAGE IS ":F8"
260    Bias=0
270    Thickn$=""
280    PRINTER IS 16
290    INPUT "ENTER DATA INPUT MODE: MANUAL or FILE",Mode$! TO GET FIRST LOT
 OF DATA
300    IF UPC$(Mode$)="M" THEN Manual
310    GOTO Read2            ! TO READ A FILE
320   !
330 Manual:Hrs=0       ! ACCEPTS NEW KEYED IN DATA
340    Dm=50
350    INPUT "ENTER INPUT DATA ARRAY LENGTH: DEFAULT=50, MAX=300",Dm
360    REDIM R(Dm),M(Dm),N(Dm)
370    INPUT "ENTER SIGNAL IDENTIFYING NAME (30 CHAR. MAX)",Name$
380    INPUT "ENTER DATE OF RUN START (yy/mm/dd)",Date$
390    INPUT "ENTER TIME OF RUN START (hh:mm:ss)",Time$
400    INPUT "ENTER ELAPSED TIME (seconds)",Span$
410    INPUT "ENTER ICE CONDITION DESCRIPTION: (18 CHAR. MAX.) ",Thickn$
420    INPUT "ENTER SIGNAL UNITS",Units$
430    INPUT "ENTER CALIBRATION IN ENGINEERING UNITS PER BIN",Cal
440    INPUT "ENTER PHYSICAL DAMAGE LIMIT",Yield
450    INPUT "ENTER HYSTERESIS SETTING IN BINS",Hys
460   !
470    PRINTER IS 16
480    PRINT PAGE
490    PRINT "ENTER DATAMYTE RANGE COLUMN"
500    PRINT "ENTER CONT WHEN DONE"
510    CALL Inlist("RANGE",R(*),Dm)
520   !
530    PRINT PAGE
540    PRINT "ENTER DATAMYTE MEAN COLUMN"
550    PRINT "ENTER CONT WHEN DONE"
560    CALL Inlist("MEAN",M(*),Dm)
570   !
580    PRINT PAGE
590    PRINT "ENTER DATAMYTE COUNT COLUMN"
600    PRINT "ENTER CONT WHEN DONE"
610    CALL Inlist("COUNT",N(*),Dm)
620   !
630 Function:  ! TO CHOOSE OPTIONS
640    PRINTER IS 16
650    Fn$="CONT"
```

```
660    INPUT "READ ADD LIST EDIT FILE CALC PLOT DUMP SCALE I
NTER NUM",Fn$
670    IF UPC$(Fn$[1,1])="R" THEN Read2
680    IF UPC$(Fn$[1,1])="A" THEN Calc1
690    IF UPC$(Fn$[1,1])="E" THEN Edit
700    IF UPC$(Fn$[1,1])="L" THEN List
710    IF UPC$(Fn$[1,1])="F" THEN File
720    IF UPC$(Fn$[1,1])="C" THEN Calc1
730    IF UPC$(Fn$[1,1])="P" THEN Displ
740    IF UPC$(Fn$[1,1])="D" THEN Dump1
750    IF UPC$(Fn$[1,1])="S" THEN Scale1
760    IF UPC$(Fn$[1,1])="I" THEN Interpolate
770    IF UPC$(Fn$[1,1])="N" THEN Number_ipi
780    PRINT PAGE
790    BEEP
800    PRINT "UNRECOGNIZED INPUT: RE-ENTER"
810    GOTO Function
820  !
830 Read2:CALL Read2(Name$,Date$,Time$,Span$,Thickn$,Units$,Cal,Yield,R(*),M(*),
N(*),Hys,Bias,Dm)
840    GOTO Function
850  !
860 List:PRINT PAGE
870    Hard_copy$=""
880    STANDARD
890    INPUT "INPUT H FOR HARD COPY OR CONT ",Hard_copy$
900    IF UPC$(Hard_copy$[1,1])="H" THEN PRINTER IS 0
910    PRINT TAB(15),"DATAMYTE 400 HISTOGRAM FOR "&Name$
920    PRINT TAB(15),"DATA COLLECTION BEGUN AT "&Time$&" ON "&Date$
930    Days$=VAL$(VAL(Span$)/86400)!SECONDS TO DAYS
940    PRINT TAB(15),"ELAPSED TIME DURING DATA COLLECTION: "&Days$&" DAYS"
950    IF Thickn$<>"" THEN PRINT TAB(15),"ICE CONDITION DURING DATA COLLECTION:
";Thickn$
960    PRINT TAB(15),"PHYSICAL DAMAGE LIMIT:";Yield;Units$
970    PRINT TAB(15),"CALIBRATION:";Cal;Units$&" / BIN"
980    PRINT TAB(15),"HYSTERESIS:";Hys;TAB(45),"BIAS: ";Bias
990    PRINT
1000   IF UPC$(Hard_copy$[1,1])<>"H" THEN
1010      DISP "PRESS CONT WHEN READY"
1020      PAUSE
1030   END IF
1040   I=0
1050 Page:IF UPC$(Hard_copy$[1,1])<>"H" THEN PRINT PAGE
1060   PRINT TAB(12),"INDEX",TAB(30);"RANGE";TAB(49);"MEAN";TAB(66);"COUN
T"
1070 !
1080 Next_copy:FOR J=1 TO 18
1090      I=I+1
1100      IF I>Dm THEN GOTO Function
1110      PRINT TAB(13);I;TAB(29);R(I);TAB(46);M(I);TAB(61);N(I)
1120 Loop_j:NEXT J
1130 Pause:IF UPC$(Hard_copy$[1,1])<>"H" THEN
1140      DISP "PRESS CONT WHEN READY"
1150      PAUSE
1160   ELSE
1170      GOTO Next_copy
1180   END IF
1190   GOTO Page
1200 !
1210 Edit: !
1220   DISP "SIGNAL IDENTIFYING NAME: ";Name$;"  RE-ENTER or CONT";
1230   INPUT Name$
1240   DISP "DATE OF RUN START: ";Date$;"  RE-ENTER or CONT";
1250   INPUT Date$
1260   DISP "TIME OF RUN START: ";Time$;"  RE-ENTER or CONT";
1270   INPUT Time$
```

```
1280   DISP "ELAPSED TIME: (seconds) ";Span$;"  RE-ENTER or CONT";
1290   INPUT Span$
1300   DISP "ICE CONDITION DESCRIPTOR: ";Thickn$;"  RE-ENTER or CONT";
1310   INPUT Thickn$
1320   DISP "SIGNAL UNITS: ";Units$;"  RE-ENTER or CONT";
1330   INPUT Units$
1340   DISP "CALIBRATION IN ENGINEERING UNITS PER BIN: ";Cal;"  RE-ENTER or CON
T";
1350   INPUT Cal
1360   DISP "PHYSICAL DAMAGE LIMIT: ";Yield;"  RE-ENTER or CONT";
1370   INPUT Yield
1380   DISP "HYSTERESIS SETTING IN BINS: ";Hys;"  RE-ENTER or CONT";
1390   INPUT Hys
1400 !
1410   Nm$="CONT"
1420   INPUT "ENTER RANGE(I), MEAN(I), NCOUNT(I) or CONT",Nm$
1430   IF Nm$="CONT" THEN Function
1440   I=POS(Nm$,"(")
1450   J=POS(Nm$,")")
1460   IF (J>=I+2) AND (I<>0) THEN Subscript_found
1470 Error:PRINT
1480   BEEP
1490   PRINT "UNRECOGNIZED INPUT: RE-ENTER"
1500   GOTO Edit
1510 !
1520 Subscript_found:I=VAL(Nm$[I+1,J-1])
1530   IF I<=Dm THEN Var
1540   BEEP
1550   PRINT "MAXIMUM SUBSCRIPT IS "&VAL$(Dm)&": RE-ENTER"
1560   GOTO Edit
1570 Var: !
1580   IF POS(Nm$,"R")<>0 THEN Var$="R("
1590   IF POS(Nm$,"M")<>0 THEN Var$="M("
1600   IF POS(Nm$,"N")<>0 THEN Var$="N("
1610   IF (POS(Nm$,"R")=0) AND (POS(Nm$,"M")=0) AND (POS(Nm$,"N")=0) THEN GOTO E
rror
1620 !
1630 Value:DISP Var$&VAL$(I)&") =";
1640   V$="CONT"
1650   INPUT V$
1660   IF V$="CONT" THEN GOTO Edit
1670   IF POS(Nm$,"R")<>0 THEN R(I)=VAL(V$)
1680   IF POS(Nm$,"M")<>0 THEN M(I)=VAL(V$)
1690   IF POS(Nm$,"N")<>0 THEN N(I)=VAL(V$)
1700   PRINT Var$&VAL$(I)&") = ";VAL(V$)
1710   I=I+1
1720   GOTO Value
1730 !
1740 File:Hrs=0
1750   CALL File(Name$,Date$,Time$,Span$,Thickn$,Units$,Cal,Yield,R(*),M(*),N(*)
,Hys,Bias,Dm)
1760   GOTO Function
1770 !
1780 Calc1:!
1790   Addflag=0
1800   IF UPC$(Fn$[1,1])="A" THEN
1810      Addflag=1
1820      Span$=VAL$(VAL(Span$)+VAL(Temp_span$))
1830      Date$=Temp_date$
1840      Time$=Temp_time$
1850   ELSE
1860      MAT Bin=ZER
1870      Temp_date$=Date$
1880      Temp_time$=Time$
1890   END IF
1900   Temp_span$=Span$
```

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: "HIST 13" PROGRAM LISTING APPENDIX D

```
1910   IF (Scflag=1) AND (UPC$(Fn$[1,1])="A") THEN
1920     PRINTER IS 16
1930     PRINT "WARNING: YOU ARE ADDING TO A SCALED HISTOGRAM"
1940     INPUT "ENTER R TO RE-ENTER OR CONT",Inpt$
1950     IF UPC$(Inpt$[1,1])="R" THEN GOTO Function
1960   END IF
1970 !
1980   Scflag=0
1990   INPUT "ENTER: DESIRED MEAN BIAS (NUMBER OF BINS) or CONT",Bias
2000   Bias=Bias+16
2010   FOR I=1 TO Dm
2020     IF R(I)=0 THEN Funct
2030     Binup=M(I)+Bias+R(I)*.5
2040     J=INT(Binup)
2050     IF FRACT(Binup)=0 THEN
2060       K=J-R(I)
2070       IF POS(Name$,"TORQUE")<>0 THEN
2080         IF J>32 THEN Bad_data
2090         Bin(J)=Bin(J)+N(I)
2100       ELSE
2110         IF (J>32) OR (K<1) THEN Bad_data
2120         IF M(I)+Bias>=17 THEN
2130           Bin(J)=Bin(J)+N(I)
2140         ELSE
2150           Bin(K)=Bin(K)+N(I)
2160         END IF
2170       END IF
2180     ELSE
2190 Distribute:  ! TO HANDLE ODD NUMBERED RANGES
2200       K=J-R(I)+1
2210       IF POS(Name$,"TORQUE")<>0 THEN
2220         IF J+1>32 THEN Bad_data
2230         Bin(J)=Bin(J)+INT(N(I)/2+.5)
2240         IF FRACT(N(I)/2)=0 THEN
2250           Bin(J+1)=Bin(J+1)+INT(N(I)/2+.5)
2260         ELSE
2270           Bin(J+1)=Bin(J+1)+INT(N(I)/2+.5)-1
2280         END IF
2290       ELSE
2300         IF (J+1>32) OR (K-1<1) THEN Bad_data
2310         IF M(I)+Bias>=17 THEN
2320           Bin(J)=Bin(J)+INT(N(I)/2+.5)
2330           IF FRACT(N(I)/2)=0 THEN
2340             Bin(J+1)=Bin(J+1)+INT(N(I)/2+.5)
2350           ELSE
2360             Bin(J+1)=Bin(J+1)+INT(N(I)/2+.5)-1
2370           END IF
2380         ELSE
2390           Bin(K)=Bin(K)+INT(N(I)/2+.5)
2400           IF FRACT(N(I)/2)=0 THEN
2410             Bin(K-1)=Bin(K-1)+INT(N(I)/2+.5)
2420           ELSE
2430             Bin(K-1)=Bin(K-1)+INT(N(I)/2+.5)-1
2440           END IF
2450         END IF
2460       END IF
2470     END IF
2480     GOTO Skip_bin
2490 Bad_data:   !
2500     DISP "PEAK OUTSIDE OF EXPECTED RANGE"
2510     BEEP
2520 Skip_bin:NEXT I
2530 Funct:Bias=Bias-16
2540   GOTO Function
2550 !
2560 Number_ipi: !
```

```
2570     IF Scflag=1 THEN
2580        PRINTER IS 16
2590        PRINT "WARNING YOU ARE CALCULATING THE IPI FOR SUMMED DATA "
2600        PRINT "THIS CAN NOT BE DONE"
2610        GOTO Function
2620     END IF
2630     Which$=""
2640     Variable=0
2650     INPUT "DO YOU WANT TO USE 25% OF MEAN AS THE RANGE : Y or CONT",Which$
2660     IF UPC$(Which$[1,1])="Y" THEN
2670        IF POS(Name$,"TORQUE")<>0 THEN
2680           INPUT "INPUT: MINIMUM MEAN BIN : Min_mean",Min_mean
2690           Variable=1
2700        ELSE
2710           INPUT "INPUT: MAXIMUM MEAN BIN : Min_mean",Min_mean
2720           Variable=1
2730        END IF
2740     ELSE
2750        IF POS(Name$,"TORQUE")<>0 THEN
2760           INPUT "INPUT: MINIMUM MEAN BIN , MINIMUM RANGE : Min_mean,Min_range
",Min_mean,Min_range
2770        ELSE
2780           INPUT "INPUT: MAXIMUM MEAN BIN , MINIMUM RANGE : Min_mean,Min_range
",Min_mean,Min_range
2790        END IF
2800     END IF
2810     Ipi_count=0
2820     Min_mean=Min_mean-17
2830     IF POS(Name$,"TORQUE")<>0 THEN
2840        IF Variable THEN
2850           FOR I=1 TO Dm
2860              IF (M(I)>=Min_mean) AND (R(I)>=INT(ABS(Min_mean+17)*.25+.5)) THE
N
2870                 Ipi_count=Ipi_count+N(I)
2880              END IF
2890           NEXT I
2900        ELSE
2910           FOR I=1 TO Dm
2920              IF (M(I)>=Min_mean) AND (R(I)>=Min_range) THEN
2930                 Ipi_count=Ipi_count+N(I)
2940              END IF
2950           NEXT I
2960        END IF
2970     ELSE
2980        IF Variable THEN
2990           FOR I=1 TO Dm
3000              IF (M(I)<=Min_mean) AND (R(I)>=INT(ABS(Min_mean+17)*.25+.5)) THE
N
3010                 Ipi_count=Ipi_count+N(I)
3020              END IF
3030           NEXT I
3040        ELSE
3050           FOR I=1 TO Dm
3060              IF (M(I)<=Min_mean) AND (R(I)>=Min_range) THEN
3070                 Ipi_count=Ipi_count+N(I)
3080              END IF
3090           NEXT I
3100        END IF
3110     END IF
3120     Inpt$=""
3130     Min_mean=Min_mean+17
3140     INPUT "DO YOU WANT HARDCOPY ? : Y or CONT",Inpt$
3150     IF UPC$(Inpt$[1,1])="Y" THEN PRINTER IS 0
3160     PRINT "COUNT OF NUMBER OF ICE PROPELLER INTERACTIONS FOR ";Name$
3170     PRINT "BASED UPON DATA COLLECTION BEGUN AT ";Time$;" ON ";Date$
3180     Days$[1,8]=VAL$(VAL(Span$)/86400)  ! SECONDS TO DAYS
```

```
3190   PRINT "ELAPSED TIME DURING DATA COLLECTION : ";Days$;" DAYS"
3200   PRINT "CALIBRATION : ";Cal;Units$;" / BIN"
3210   IF POS(Name$,"TORQUE")<>0 THEN
3220      PRINT "SUBJECT TO THE CONDITIONS : MEAN BIN >= ";Min_mean;" BINS"
3230   ELSE
3240      PRINT "SUBJECT TO THE CONDITIONS : MEAN BIN <= ";Min_mean;" BINS"
3250   END IF
3260   IF Variable THEN
3270      PRINT " AND BIN RANGE >= 25% OF NOMINAL BIN"
3280   ELSE
3290      PRINT " AND BIN RANGE >= ";Min_range;" BINS"
3300   END IF
3310   PRINT
3320   PRINT "NUMBER OF IPI COUNTED = ";Ipi_count
3330   PRINT "NUMBER IF IPI PER MINUTE FOR THIS PERIOD = ";Ipi_count/VAL(Span$)*
60
3340   PRINT
3350   PRINT
3360   PRINT
3370   PRINTER IS 1
3380   GOTO Function
3390   !
3400 Displ:PRINTER IS 16
3410   PRINT PAGE
3420   CALL Table1(Name$,Date$,Time$,Span$,Thickn$,Units$,Cal,Yield,Bin(*),Yrs,H
yr,Hrs,Scflag,Ts,Hys,Bias,Lines)
3430   Nm$="CONT"
3440   INPUT "ENTER HIST OR CONT",Nm$
3450   IF UPC$(Nm$[1,1])<>"H" THEN Function
3460 !
3470   IF Addflag=1 THEN INPUT "ENTER HISTOGRAM NAME (30 CHAR. MAX.)",Name$
3480   PRINT PAGE
3490   CALL Hist1(Name$,Date$,Units$,Cal,Yield.Bin(*),Hrs,Scflag,Ts,Hys)
3500   PAUSE
3510   EXIT GRAPHICS
3520   Nm$="CONT"
3530   INPUT "ENTER DUMP OR CONT",Nm$
3540   IF UPC$(Nm$[1,1])<>"D" THEN Function
3550 !
3560 Dumpl:PRINTER IS 0
3570   CALL Table1(Name$,Date$,Time$,Span$,Thickn$,Units$,Cal,Yield.Bin(*),Yrs,H
yr,Hrs,Scflag,Ts,Hys,Bias,Lines)
3580   IF Lines>26 THEN PRINT PAGE
3590   FOR I=Lines TO 26
3600      PRINT
3610   NEXT I
3620   SETGU
3630   DUMP GRAPHICS 5,95
3640   PRINT PAGE
3650   PRINTER IS 16
3660   GOTO Function
3670 !
3680 Scale1: !
3690   INPUT "ENTER DATA SCALING TIME INTERVAL (SECONDS) ",Ts
3700   Sc=Ts/VAL(Span$)
3710   FOR I=1 TO 32
3720      Bin(I)=Bin(I)*Sc
3730   NEXT I
3740   Scflag=1
3750   GOTO Function
3760 !
3770 Interpolate:   ! FOR PREDICTING FAILURE LIFE
3780   INPUT "ENTER CORRECTED ELAPSED SHIP RUNNING TIME (seconds) OR CONT",Spa
n$
3790   INPUT "ENTER NUMBER OF SHIP RUNNING HOURS PER YEAR",Hyr
3800   INPUT "ENTER NUMBER OF YEARS FOR WHICH THIS LOAD HISTORY IS TO BE EXTRAPO
```

```
LATED",Yrs
3810   INPUT "ENTER MEAN ICE THICKNESS DURING DATA COLLECTION",Thickn$
3820   Hrs=Hyr*Yrs
3830   Ratio=Hrs/VAL(Span$)
3840   IF POS(Name$,"RENK")<>0 THEN Ratio=Ratio*150/4
3850 !
3860   DIM X(16),Y(16)
3870 Xyloop1:J=0
3880   FOR I=16-Hys TO 1 STEP -1
3890      IF Bin(I)=0 THEN Reg1
3900      J=J+1
3910      X(J)=(I-16.5)*Cal
3920      Y(J)=LGT(Bin(I))
3930   NEXT I
3940   GOTO Mult1
3950 !
3960 Reg1:IF I=16-Hys THEN Xyloop2
3970   IF Y(J)=0 THEN Regr1
3980   J=J+1
3990   X(J)=(I-16.5)*Cal
4000   Y(J)=0
4010 !
4020 Regr1:Nr=J
4030   GOSUB Reg
4040 !
4050 Mult1:FOR I=16-Hys TO 1 STEP -1
4060      IF Bin(I)=0 THEN Line_loop1
4070      Bin(I)=INT(Bin(I)*Ratio)
4080   NEXT I
4090   IF I<=1 THEN Xyloop2
4100 !
4110 Line_loop1:FOR I=I TO 1 STEP -1
4120      Unsc=10^((I-16.5)*Cal*C1+C2)
4130      Bin(I)=INT(Ratio*Unsc)
4140      FIXED 6
4150      PRINT "I =";I;" X =";(I-16.5)*Cal;" UNSC =";Unsc;" SC =";Bin(I)
4160      STANDARD
4170      IF Bin(I)=0 THEN Xyloop2
4180   NEXT I
4190 !
4200 Xyloop2:J=0
4210   FOR I=17+Hys TO 32
4220      IF Bin(I)=0 THEN Reg2
4230      J=J+1
4240      X(J)=(I-16.5)*Cal
4250      Y(J)=LGT(Bin(I))
4260   NEXT I
4270   GOTO Mult2
4280 !
4290 Reg2:IF I=17+Hys THEN Function
4300   IF Y(J)=0 THEN Regr2
4310   J=J+1
4320   X(J)=(I-16.5)*Cal
4330   Y(J)=0
4340 !
4350 Regr2:Nr=J
4360   GOSUB Reg
4370 !
4380 Mult2:FOR I=17+Hys TO 32
4390      IF Bin(I)=0 THEN Line_loop2
4400      Bin(I)=INT(Bin(I)*Ratio)
4410   NEXT I
4420   IF I>=32 THEN Function
4430 !
4440 Line_loop2: !
4450   FOR I=I TO 32
```

```
4460       Unsc=10^((I-16.5)*Cal*C1+C2)
4470       Bin(I)=INT(Unsc*Ratio)
4480       FIXED 6
4490       STANDARD
4500       IF Bin(I)<=0 THEN Function
4510    NEXT I
4520    GOTO Function
4530 !
4540 Reg:Sx=Sy=Sxx=Syy=Sxy=0
4550    FOR I=1 TO Nr
4560       Sx=Sx+X(I)
4570       Sy=Sy+Y(I)
4580       Sxx=Sxx+X(I)^2
4590       Syy=Syy+Y(I)^2
4600       Sxy=Sxy+X(I)*Y(I)
4610    NEXT I
4620 !
4630    C1=(Sxy-Sx*Sy/Nr)/(Sxx-Sx^2/Nr)
4640    C2=(Sy-C1*Sx)/Nr
4650    R=C1*SQR((Sxx-Sx^2/Nr)/(Nr-1))/SQR((Syy-Sy^2/Nr)/(Nr-1))
4660 !
4670 Temporary_block:FIXED 5
4680    PRINTER IS 0
4690    PRINT USING "//"
4700    FOR I=1 TO Nr
4710       PRINT "I =";I;" X =";X(I);" Y =";Y(I)
4720    NEXT I
4730    PRINT "C1 =";C1;" C2 =";C2;" R =";R
4740    STANDARD
4750    PRINTER IS 16
4760    RETURN
4770 !
4780 !
4790    STOP
4800    END
4810 !
4820 Input_list:   !
4830    SUB Inlist(Var$,A(*),INTEGER Dm)
4840       OPTION BASE 1
4850       INTEGER I
4860       FOR I=1 TO Dm
4870          Value=-9999
4880          DISP Var$&"("&VAL$(I)&") = ";
4890          INPUT Value
4900          IF Value=-9999 THEN SUBEXIT
4910          A(I)=Value
4920       NEXT I
4930       PRINT "MAXIMUM ARRAY SIZE IS "&VAL$(Dm)&" ELEMENTS"
4940    SUBEND
4950 !
4960 Hist1: !
4970    SUB Hist1(Name$,Date$,Units$,Cal,Yield,Bin(*),Hrs,Scflag,Ts,INTEGER Hys)
4980       OPTION BASE 1
4990       DIM Yunits$[20],Limit$[30]
5000 !
5010       UNCLIP
5020       GCLEAR
5030       Xmax=16*Cal
5040       F=1
5050 Testf:IF F*Yield<Xmax THEN Setlimit
5060       F=F-.1
5070       IF F=0 THEN No_f
5080       GOTO Testf
5090 No_f:F=1
5100 Setlimit: !
5110       IF POS(Name$,"RENK")<>0 THEN Limit$=" ULTIMATE STRENGTH"
```

```
5120      IF POS(Name$,"TORQUE")<>0 THEN Limit$=" SHEARING TORQUE"
5130      IF POS(Name$,"STRAIN")<>0 THEN Limit$=" YIELD"
5140      Lmt=F*Yield/Cal
5150 !
5160      Xmin=0
5170      Xmax=32
5180      IF Scflag=1 THEN
5190         Ymin=LGT(.00005)
5200      ELSE
5210         Ymin=LGT(.5)
5220      END IF
5230      Ymax=0                                   ! SETS Y MAX
5240      FOR I=1 TO 32
5250         IF Bin(I)>Ymax THEN Ymax=Bin(I)
5260      NEXT I
5270      Ymax=INT(LGT(Ymax))+1
5280 !
5290 Graphics:GRAPHICS
5300      GCLEAR
5310      DEG
5320      LOCATE 12,120,30,85
5330      SCALE Xmin,Xmax,Ymin,Ymax
5340      SETUU
5350      FRAME
5360 !
5370 Xlabel:CSIZE 2.5
5380      LORG 5
5390      LDIR 90
5400      FIXED 0
5410      IF POS(Name$,"TORQUE")<>0 THEN
5420         IF Hys<>0 THEN
5430            Rl=0
5440            Rh=0+INT((Hys+1)/2+.5)
5450            MOVE Rh,Ymax
5460            PLOT Rh,Ymin,-1
5470            MOVE (Rh-Rl)/2+Rl,(Ymax+Ymin)*.5
5480            LABEL USING "K";"THRESHOLD REJECTION BAND"
5490         END IF
5500         MOVE 159.9/Cal,Ymin          ! PLOTS LINE AT FULL POWER TORQUE
5510         PLOT 159.9/Cal,Ymax,-1
5520         LORG 8
5530 !
5540         Inc=(Ymax-Ymin)*.02          !PLACES TICKS ON X-AXIS
5550         FOR I=0 TO 32
5560            MOVE I,Ymax
5570            PLOT I,Ymax-Inc,-1
5580            MOVE I,Ymin+Inc
5590            PLOT I,Ymin,-1
5600            MOVE I,Ymin-Inc
5610            LABEL USING "K";VAL$(I*Cal)! LABLES X-AXIS
5620         NEXT I
5630         STANDARD
5640 !
5650         Inc=(Ymax-Ymin)*.21
5660      ELSE
5670 !
5680 Plot_thrust: ! X-AXIS FOR THRUST HISTOGRAMS
5690         IF Hys<>0 THEN
5700            Rl=16-INT((Hys+1)/2+.5)
5710            Rh=16+INT((Hys+1)/2+.5)
5720            MOVE Rl,Ymax
5730            PLOT Rl,Ymin,-1
5740            MOVE Rh,Ymax
5750            PLOT Rh,Ymin,-1
5760            MOVE 16,(Ymax+Ymin)*.5
5770            LABEL USING "K";"THRESHOLD REJECTION BAND"
```

```
5780            END IF
5790 !
5800            Inc=(Ymax-Ymin)*.02! PLACES TICKS ON X-AXIS
5810            LORG 8
5820            FOR I=0 TO 32
5830               MOVE I,Ymax
5840               PLOT I,Ymax-Inc,-1
5850               MOVE I,Inc+Ymin
5860               PLOT I,Ymin,-1
5870               MOVE I,-Inc+Ymin
5880               LABEL USING "K";VAL$((I-16)*Cal)
5890            NEXT I
5900            STANDARD
5910 !
5920            LDIR 0
5930            Inc=(Ymax-Ymin)*.21
5940            IF POS(Name$,"STRESS")<>0 THEN Xvar
5950            LORG 2
5960            MOVE 0,Ymin-Inc
5970            LABEL USING "K";"-COMPRESSION-"  !LABLES UNDER THRUST PLOT
5980            LORG 8
5990            MOVE 32,Ymin-Inc
6000            LABEL USING "K";"-TENSION-"
6010   !
6020      END IF
6030   !
6040 Xvar:CSIZE 3
6050      LORG 5
6060      LDIR 0
6070      MOVE 16,Ymin-Inc
6080      LABEL USING "K";"PEAK AMPLITUDE ("&Units$&")"
6090      CSIZE 2.8
6100 !
6110 Ylabel:CSIZE 2.5
6120      LORG 8
6130      FIXED 0
6140      Inc=(Xmax-Xmin)*.012
6150      IF (Ymax<=1) OR (Scflag=1) THEN Small_label
6160      IF Ymax<8 THEN N_label
6170      FOR Y=0 TO Ymax
6180         CALL Ylabel(Y,Inc,Rl,Rh,1)
6190      NEXT Y
6200      GOTO Axis_name
6210 !
6220 Small_label: !
6230      FOR Y=LGT(.0001) TO Ymax-1
6240         CALL Ylabel(Y,Inc,Rl,Rh,2)
6250         CALL Ylabel(Y+LGT(2),Inc,Rl,Rh,2)
6260         CALL Ylabel(Y+LGT(5),Inc,Rl,Rh,2)
6270      NEXT Y
6280      CALL Ylabel(Ymax,Inc,Rl,Rh,2)
6290      GOTO Axis_name
6300 N_label:FOR Y=0 TO Ymax-1
6310         CALL Ylabel(Y,Inc,Rl,Rh,0)
6320         CALL Ylabel(Y+LGT(2),Inc,Rl,Rh,0)
6330         CALL Ylabel(Y+LGT(5),Inc,Rl,Rh,0)
6340      NEXT Y
6350      CALL Ylabel(Ymax,Inc,Rl,Rh,0)
6360 !
6370 Axis_name:CSIZE 3
6380      LORG 5
6390      LDIR 90
6400      MOVE -(Xmax-Xmin)*.1+Xmin,(Ymax-Ymin)*.5+Ymin    ! LABLES Y-AXIS
6410      IF Scflag=0 THEN
6420         LABEL USING "K";"COUNTS"
6430      ELSE
```

```
6440          LABEL USING "K";"COUNTS SCALED FOR "&VAL$(Ts)&" SECONDS"
6450       END IF
6460 !
6470 Title:CSIZE 3.2
6480       LDIR 0
6490       Y=(Ymax-Ymin)*.1+Ymax
6500       MOVE (Xmax-Xmin)*.25+Xmin,Y
6510       IF (POS(Name$,"RENK")=0) OR (Hrs=0) THEN LABEL USING "K";Name$
6520       IF (POS(Name$,"RENK")<>0) AND (Hrs<>0) THEN LABEL USING "K";"RENK: ALL
 BULL WHEEL TEETH"
6530       MOVE (Xmax-Xmin)*.75+Xmin,Y
6540       IF Hrs=0 THEN
6550          LABEL USING "K";"RUN START: "&Date$
6560       ELSE
6570          LABEL USING "K";VAL$(Yrs)&" YEAR HISTORY"
6580       END IF
6590 !
6600 Plot:FOR I=1 TO 32
6610          IF (I>Rl) AND (I<=Rh) THEN Nxti! DEAD BAND
6620          IF Bin(I)=0 THEN Nxti
6630          Y=LGT(Bin(I))
6640          FOR X=I-1 TO I STEP .05
6650             MOVE X,Ymin
6660             PLOT X,Y,-1
6670          NEXT X
6680 Nxti:NEXT I
6690    SUBEND
6700 !
6710 File:     !
6720    SUB File(Nm$,Dt$,Tm$,Span$,Thk$,Units$,Cal,Yld,R(*),M(*),N(*),INTEGER Hys
,Bias,Dm)
6730       OPTION BASE 1
6740       INTEGER F1
6750 File_name: !
6760       INPUT "ENTER NAME OF HISTOGRAM DATA FILE INCLUDING DEVICE SPECIFIER",F
ile$
6770       F1=6*(18+4)+2*8+3*2+Dm*3*8
6780 Create2:ON ERROR GOTO Service
6790       CREATE File$,INT(F1/256)+1
6800       OFF ERROR
6810       ASSIGN #1 TO File$
6820       BUFFER #1
6830       PRINT #1;Nm$,Dt$,Tm$,Span$,Thk$,Units$
6840       PRINT #1;Cal,Yld
6850       PRINT #1;Hys,Bias,Dm
6860       PRINT #1;R(*)
6870       PRINT #1;M(*)
6880       PRINT #1;N(*)
6890       SUBEXIT
6900 !
6910 Service:IF ERRN<>54 THEN Message
6920       Inpt$=""
6930       INPUT "DUPLICATE FILE NAME: ENTER P TO PURGE OR CONT",Inpt$
6940       IF Inpt$<>"P" THEN File_name
6950       PURGE File$
6960       GOTO Create2
6970 Message:DISP ERRM$&" ENTER CONT TO RE-ENTER"
6980       PAUSE
6990       GOTO File_name
7000    SUBEND
7010 !
7020 Read1:    !
7030    SUB Read(Nm$,Dt$,Tm$,Span$,Thk$,Units$,Cal,Yld,R(*),M(*),N(*),INTEGER Hys
,Bias)
7040       OPTION BASE 1
7050       INPUT "ENTER NAME OF FILE FROM WHICH DATA IS TO BE READ",File$
```

```
7060       ASSIGN #1 TO File$
7070       BUFFER #1
7080       ON ERROR GOTO Read2
7090       READ #1,1;Nm$,Dt$,Tm$,Span$,Units$,Cal,Yld,Hys,Bias
7100       OFF ERROR
7110       GOTO Read3
7120 Read2:READ #1,1;Nm$,Dt$,Tm$,Span$,Thk$,Units$,Cal,Yld,Hys,Bias
7130 Read3:READ #1,2;R(*)
7140       READ #1,3;M(*)
7150       READ #1,4;N(*)
7160    SUBEND
7170 !
7180 Ylbl: !
7190    SUB Ylabel(Y,Inc,Rl,Rh,INTEGER Iop)
7200       FIXED 0
7210       MOVE Xmin-Inc,Ymin+Y
7220       IF Iop=2 THEN FIXED 4
7230       IF Iop=0 THEN LABEL USING "K";VAL$(10^Y)
7240       IF Iop=1 THEN LABEL USING "K";"10^"&VAL$(Y)
7250       IF Iop=2 THEN LABEL USING "K";VAL$(10^Y)
7260       IF FRACT(Y)<>0 THEN LINE TYPE 3
7270       MOVE 0,Y
7280       IF Rh-Rl=0 THEN
7290          PLOT 32,Y,-1
7300       ELSE
7310          PLOT Rl,Y,-1
7320          MOVE Rh,Y
7330          PLOT 32,Y,-1
7340       END IF
7350       LINE TYPE 1
7360       STANDARD
7370    SUBEND
7380 !
7390 Table1:   !
7400    SUB Table1(Name$,Date$,Time$,Span$,Thickn$,Units$,Cal,Yield,Bin(*),Yrs,Hy
r,Hrs,Scflag,Ts,INTEGER Hys,Bias,Lines)
7410       OPTION BASE 1
7420       DIM Hdr1$[42],Hdr2$[42]
7430       Hdr1$="MV R LEMEUR PROPELLER BLADE TESTS"
7440       IF (Hrs=0) AND NOT Scflag THEN Hdr2$="DATAMYTE 400 RECORDED DATA"
7450       IF (Hrs<>0) AND NOT Scflag THEN Hdr2$="EXTRAPOLATED DATAMYTE 400 LOAD
 HISTORY"
7460       IF Scflag THEN Hdr2$="DATAMYTE 400 SCALED DATA"
7470       PRINT TAB((80-LEN(Hdr1$))*.5),Hdr1$
7480       PRINT TAB((80-LEN(Hdr2$))*.5),Hdr2$
7490       PRINT
7500       PRINT TAB(15),"AMPLITUDE-FREQUENCY HISTOGRAM FOR "&Name$
7510       IF Hrs<>0 THEN PRINT TAB(15),VAL$(Yrs)&" YEAR HISTORY AT "&VAL$(Hyr)&"
 HRS PER YEAR: "&VAL$(Hrs)&" HRS TOTAL"
7520       IF (Hrs=0) AND NOT Scflag THEN PRINT TAB(15),"DATA COLLECTION BEGUN AT
 "&Time$&" ON "&Date$
7530       IF (Hrs<>0) OR Scflag THEN PRINT TAB(15),"BASED UPON DATA COLLECTION B
EGUN AT "&Time$&" ON "&Date$
7540       Days$=VAL$(VAL(Span$)/86400)!SECONDS TO DAYS
7550       PRINT TAB(15),"ELAPSED TIME DURING DATA COLLECTION: "&Days$&" DAYS"
7560       IF Scflag THEN PRINT TAB(15),"DATA SCALED FOR "&VAL$(Ts)&" SECONDS"
7570       IF Thickn$<>"" THEN PRINT TAB(15),"ICE CONDITION DURING DATA COLLECTIO
N: "&Thickn$
7580       PRINT TAB(15),"CALIBRATION:";Cal;Units$&" / BIN"
7590       IF POS(Name$,"TORQUE")<>0 THEN
7600          PRINT TAB(15),"PHYSICAL DAMAGE LIMIT: ";Yield;Units$
7610       END IF
7620       IF POS(Name$,"STRAIN")<>0 THEN
7630          PRINT TAB(15),"YIELD STRAIN AT THIS LOCATION: ";Yield;Units$
7640       END IF
7650       IF POS(Name$,"RENK")<>0 THEN
```

```
7660          PRINT TAB(15),"ULTIMATE STRENGTH OF GEAR TEETH: ";Yield;Units$
7670       END IF
7680       IF POS(Name$,"TORQUE")<>0 THEN
7690          PRINT TAB(15),"TORQUE TO SHEAR RUDDER STOCK: ";Yield;Units$
7700       END IF
7710 Hys: !
7720       PRINT TAB(15),"HYSTERESIS:";Hys;TAB(45),"BIAS: ";Bias
7730       PRINT
7740       PRINT TAB(14);"BIN";TAB(29);"COUNT";TAB(58);"RANGE"
7750       PRINT TAB(55-LEN(Units$)*.5);"("&Units$&")"
7760       Lines=11
7770       FOR I=1 TO 32
7780          IF (POS(Name$,"THRUST")<>0) AND (16-Hys<I) AND (I<17+Hys) THEN Inc_
i! SURPRESSES PRINTOUT OF DEAD BAND FIGURES
7790          IF Bin(I)=0 THEN Inc_i
7800          Lines=Lines+1
7810          IF POS(Name$,"THRUST")=0 THEN
7820             PRINT TAB(14);I;TAB(27);Bin(I);TAB(46);(I-1)*Cal;TAB(62);I*Cal
7830          ELSE
7840             PRINT TAB(14);I;TAB(27);Bin(I);TAB(46);(I-17)*Cal;TAB(62);(I-16)
*Cal
7850          END IF
7860 Inc_i:NEXT I
7870    SUBEND
7880 !
7890 Read2:    !
7900    SUB Read2(Nm$,Dt$,Tm$,Span$,Thk$,Units$,Cal,Yld,R(*),M(*),N(*),INTEGER Hy
s,Bias,Dm)
7910       OPTION BASE 1
7920       INTEGER F1
7930       INPUT "ENTER NAME OF FILE FROM WHICH TO READ DATA",File$
7940       ASSIGN #1 TO File$
7950       BUFFER #1
7960       READ #1;Nm$,Dt$,Tm$,Span$,Thk$,Units$
7970       READ #1;Cal,Yld
7980       READ #1;Hys,Bias,Dm
7990       REDIM R(Dm),M(Dm),N(Dm)
8000       READ #1;R(*),M(*),N(*)
8010       ASSIGN #1 TO *
8020       SUBEXIT
8030    SUBEND
```

```
10     REM PROGRAM *HIST*/ VERSION 14/ MHE/KPK 84/11/20
20     REM SAME AS VERSION 12 EXCEPT USES STRUCTURED PROGRAMMING
30     REM FOR USE ON HP9845C COMPUTER
40     REM PROGRAM TO CALCULATE AND PLOT AMPLITUDE-FREQUENCY HISTOGRAMS
50     REM USING DATAMYTE 400 COUNTS AT LEVEL HISTOGRAMS AS INPUT
60     REM *HIST12* IS FOR TORQUE AND THRUST WAVEFORMS
70     REM ONLY VERSIONS HIST11 AND HIST12 HANDLE ODD NUMBERED RANGES
80     REM PROPERLY
90   !
100    OPTION BASE 1
110    INTEGER I,J,Scale_flag,Lines,Counts
120    DIM Temp(32,2) ! FOR READING , STORING FILES AND TRANSFERRING FILES
130    DIM Bin(32,2)                             ! DATA FILES
140    DIM Scaled_bin(32,2)                      ! PER CENT DATA FILES
150    DIM Name$[30]
160    MASS STORAGE IS ":F8"
170    Thickn$=""
180    PRINTER IS 16
190    INPUT "ENTER DATA INPUT MODE: MANUAL or FILE",Mode$! TO GET FIRST LOT
 OF DATA
200    IF UPC$(Mode$[1,1])="F" THEN Read1
210  !
220 Manual:      ! ACCEPTS NEW KEYED IN DATA
230    INPUT "ENTER SIGNAL IDENTIFYING NAME (30 CHAR. MAX)",Name$
240    INPUT "ENTER DATE OF RUN START (yy/mm/dd)",Date$
250    INPUT "ENTER TIME OF RUN START (hh:mm:ss)",Time$
260    INPUT "ENTER ELAPSED TIME (seconds)",Span$
270    INPUT "ENTER ICE CONDITION DESCRIPTION: (18 CHAR. MAX.) ",Thickn$
280    INPUT "ENTER SIGNAL UNITS",Units$
290    INPUT "ENTER CALIBRATION IN ENGINEERING UNITS PER BIN",Cal
300    MAT Bin=ZER
310    FOR I=1 TO 32
320       DISP "ENTER BIN (";I-1;") COUNTS  or CONT ";
330       INPUT Bin(I,1)
340    NEXT I
350    FOR I=1 TO 32
360       DISP "ENTER BIN (";I-1;") LEVEL CROSSINGS  or CONT ";
370       INPUT Bin(I,2)
380    NEXT I
390    GOTO Scale_data
400  !
410 Function:  ! TO CHOOSE OPTIONS
420    Fn$="CONT"
430    INPUT "ENTER: READ ADD LIST EDIT FILE PLOT or DUMP",Fn$
440    IF UPC$(Fn$[1,1])="R" THEN Read1
450    IF UPC$(Fn$[1,1])="A" THEN Sum1
460    IF UPC$(Fn$[1,1])="E" THEN Edit
470    IF UPC$(Fn$[1,1])="L" THEN List
480    IF UPC$(Fn$[1,1])="F" THEN File
490    IF UPC$(Fn$[1,1])="P" THEN Displ
500    IF UPC$(Fn$[1,1])="D" THEN Dump1
510    PRINT PAGE
520    PRINT "UNRECOGNIZED INPUT: RE-ENTER"
530    GOTO Function
540  !
550 Read1:Addflag=0
560 Read2:CALL Read2(Name$,Temp_date$,Temp_time$,Temp_span$,Thickn$,Units$,Cal,T
emp(*))
570    IF NOT Addflag THEN
580       MAT Bin=Temp
590       Span$=Temp_span$
600       Date$=Temp_date$
610       Time$=Temp_time$
620    ELSE
630       Span$=VAL$(VAL(Span$)+VAL(Temp_span$))
640       FOR I=1 TO 32
```

```
650         FOR J=1 TO 2
660            Bin(I,J)=Bin(I,J)+Temp(I,J)
670         NEXT J
680      NEXT I
690   END IF
700 Scale_data: !          TO GET MATRIX OF PER CENT READINGS
710   C_total=0
720   L_total=0
730   FOR I=1 TO 32
740      C_total=C_total+Bin(I,1)
750      L_total=L_total+Bin(I,2)
760   NEXT I
770   FOR I=1 TO 32
780      Scaled_bin(I,1)=Bin(I,1)/C_total*100 ! PER CENT OF TOTAL
790      Scaled_bin(I,2)=Bin(I,2)/L_total*100 ! PER CENT OF TOTAL
800   NEXT I
810   Counts=INT((C_total/VAL(Span$)+.5)/10)*10
820   GOTO Function
830   !
840 List:PRINTER IS 16
850   PRINT PAGE
860   NORMAL
870   Inpt$=""
880   INPUT "PRINT H FOR HARD COPY OR CONT ",Inpt$
890   IF UPC$(Inpt$[1,1])="H" THEN PRINTER IS 0
900   PRINT LIN(5)
910   PRINT TAB(15),"DATAMYTE 400 HISTOGRAM FOR "&Name$
920   PRINT TAB(15),"DATA COLLECTION BEGUN AT "&Time$&" ON "&Date$
930   Days$=VAL$(VAL(Span$)/86400)      !SECONDS TO DAYS
940   PRINT TAB(15),"ELAPSED TIME DURING DATA COLLECTION: "&Days$&" DAYS"
950   IF Thickn$<>"" THEN PRINT TAB(15),"ICE CONDITION DURING DATA COLLECTION:
";Thickn$
960   PRINT TAB(15),"CALIBRATION:";Cal;Units$&" / BIN"
970   PRINT
980   IF UPC$(Inpt$[1,1])<>"H" THEN
990      DISP "PRESS CONT WHEN READY"
1000     PAUSE
1010  END IF
1020  I=0
1030 Page:IF UPC$(Inpt$[1,1])<>"H" THEN PRINT PAGE
1040  PRINT "         INDEX      COUNTS AT     PER CENT       LEVEL     PER CEN
T OF"
1050  IF Counts=800 THEN
1060     PRINT "        NUMB.      800/SEC.    OF COUNTS   CROSSINGS
LEVEL CROSSINGS"
1070  ELSE
1080     IF Counts=2400 THEN
1090        PRINT "        NUMB.      2400/SEC.    OF COUNTS   CROSSING
S LEVEL CROSSINGS"
1100     ELSE
1110        BEEP
1120        DISP "TIME SPAN PROBABLY WRONG"
1130     END IF
1140  END IF
1150 Hard_copy: !
1160  FOR J=1 TO 18
1170     I=I+1
1180     IF I>32 THEN GOTO Function
1190     PRINT USING P_list1;I,Bin(I,1),Scaled_bin(I,1),Bin(I,2),Scaled_bin(I,2
)
1200 P_list1:IMAGE 10X,3D,4X,12D,4X,3D.6D,1X,10D,4X,3D.6D
1210 Loop_j:NEXT J
1220 Pause:IF UPC$(Inpt$[1,1])<>"H" THEN
1230     DISP "PRESS CONT WHEN READY"
1240     PAUSE
1250  ELSE
```

```
1260        GOTO Hard_copy
1270     END IF
1280     GOTO Page
1290  !
1300  Edit: !
1310     DISP "SIGNAL IDENTIFYING NAME: ";Name$;"  RE-ENTER OR CONT";
1320     INPUT Name$
1330     DISP "DATE OF RUN START: ";Date$;"  RE-ENTER OR CONT";
1340     INPUT Date$
1350     DISP "TIME OF RUN START: ";Time$;"  RE-ENTER OR CONT";
1360     INPUT Time$
1370     DISP "ELAPSED TIME: (seconds) ";Span$;"  RE-ENTER OR CONT";
1380     INPUT Span$
1390     DISP "ICE CONDITION DESCRIPTOR: ";Thickn$;"  RE-ENTER OR CONT";
1400     INPUT Thickn$
1410     DISP "SIGNAL UNITS: ";Units$;"  RE-ENTER OR CONT";
1420     INPUT Units$
1430     DISP "CALIBRATION IN ENGINEERING UNITS PER BIN: ";Cal;"  RE-ENTER OR CON
T";
1440     INPUT Cal
1450  !
1460     Change$="N"
1470     INPUT "DO YOU WANT TO MODIFY DATA Y OR CONT",Change$
1480     IF UPC$(Change$[1,1])="N" THEN Scale_data
1490  !
1500     FOR I=1 TO 32
1510        DISP " COUNTS (";I-1;") = ";Bin(I,1);"  RE-ENTER OR CONT";
1520        INPUT Bin(I,1)
1530     NEXT I
1540     FOR I=1 TO 32
1550        DISP " LEVEL CROSSINGS (";I-1;") = ";Bin(I,2);"  RE-ENTER OR CONT";
1560        INPUT Bin(I,2)
1570     NEXT I
1580     GOTO Scale_data
1590   !
1600  File: !
1610     CALL File(Name$,Date$,Time$,Span$,Thickn$,Units$,Cal,Bin(*))
1620     GOTO Function
1630  !
1640  Sum1:!
1650     Addflag=1
1660     GOTO Read2
1670  !
1680  Disp1:PRINTER IS 16
1690     PRINT PAGE
1700     Scale_flag=0
1710     Inpt$=" "
1720     INPUT "INPUT S FOR SCALED DATA OR CONT ",Inpt$
1730     IF UPC$(Inpt$[1,1])="S" THEN Scale_flag=1
1740     INPUT "ENTER COUNTS OR LEVEL CROSSINGS",Type$
1750     IF UPC$(Inpt$[1,1])<>"S" THEN
1760        CALL Table1(Type$,Name$,Date$,Time$,Span$,Thickn$,Units$,Cal,Bin(*),Sc
ale_flag,Lines,Counts)
1770     ELSE
1780        CALL Table1(Type$,Name$,Date$,Time$,Span$,Thickn$,Units$,Cal,Scaled_bi
n(*),Scale_flag,Lines,Counts)
1790     END IF
1800     Nm$="CONT"
1810     INPUT "ENTER HIST OR CONT",Nm$
1820     IF UPC$(Nm$[1,1])<>"H" THEN Function
1830  !
1840     IF Addflag=1 THEN INPUT "ENTER HISTOGRAM NAME (30 CHAR. MAX.) or CONT",
Name$
1850     PRINT PAGE
1860     IF UPC$(Inpt$[1,1])<>"S" THEN
1870        CALL Hist1(Type$,Name$,Date$,Units$,Cal,Bin(*),Scale_flag,Counts)
```

```
1880   ELSE
1890      CALL Hist1(Type$,Name$,Date$,Units$,Cal,Scaled_bin(*),Scale_flag,Count
s)
1900   END IF
1910   PAUSE
1920   EXIT GRAPHICS
1930   Nm$="CONT"
1940   INPUT "ENTER DUMP OR CONT",Nm$
1950   IF UPC$(Nm$[1,1])<>"D" THEN Function
1960 !
1970 Dump1:PRINTER IS 0
1980   IF UPC$(Inpt$[1,1])<>"S" THEN
1990      CALL Table1(Type$,Name$,Date$,Time$,Span$,Thickn$,Units$,Cal,Bin(*),Sc
ale_flag,Lines,Counts)
2000   ELSE
2010      CALL Table1(Type$,Name$,Date$,Time$,Span$,Thickn$,Units$,Cal,Scaled_bi
n(*),Scale_flag,Lines,Counts)
2020   END IF
2030   IF Lines>26 THEN PRINT PAGE
2040   FOR I=Lines TO 26
2050      PRINT
2060   NEXT I
2070   SETGU
2080   DUMP GRAPHICS 5,95
2090   PRINT PAGE
2100   PRINTER IS 16
2110   GOTO Function
2120 !
2130 !
2140   STOP
2150   END
2160 !
2170 Hist1: !
2180   SUB Hist1(Type$,Name$,Date$,Units$,Cal,Temp(*),INTEGER Scflag,INTEGER Cou
nts)
2190      OPTION BASE 1
2200      DIM Yunits$[20]
2210      INTEGER Col
2220 !
2230      IF UPC$(Type$[1,1])="C" THEN Col=1
2240      IF UPC$(Type$[1,1])="L" THEN Col=2
2250      Xmax=32
2260      Ymax=0      ! SETS MAXIMUM Y VALUE
2270      FOR I=1 TO 32
2280         IF Temp(I,Col)>Ymax THEN Ymax=Temp(I,Col)
2290      NEXT I
2300      Ymax=INT(LGT(Ymax))+1
2310 !
2320 Graphics:GRAPHICS
2330      UNCLIP
2340      GCLEAR
2350      DEG
2360      LOCATE 12,120,30,85
2370      IF Scflag THEN
2380         Ymin=LGT(.0000005)
2390      ELSE
2400         Ymin=LGT(.5)
2410      END IF
2420      Xmin=0
2430      SCALE Xmin,Xmax,Ymin,Ymax
2440      SETUU
2450      FRAME
2460 !
2470 Xlabel:CSIZE 2.5
2480      LORG 8
2490      LDIR 90
```

```
2500       FIXED 0
2510       IF POS(Name$,"TORQUE")<>0 THEN
2520          MOVE 159.9/Cal,Ymin! PLOTS LINE AT FULL POWER TORQUE
2530          PLOT 159.9/Cal,Ymax,-1
2540 !
2550          Inc=(Ymax-Ymin)*.02!PLACES TICKS ON X-AXIS
2560          FOR I=0 TO 32
2570             MOVE I,Ymax
2580             PLOT I,Ymax-Inc,-1
2590             MOVE I,Ymin+Inc
2600             PLOT I,Ymin,-1
2610             MOVE I,Ymin-Inc
2620             LABEL USING "K";VAL$(I*Cal)! LABLES X-AXIS
2630          NEXT I
2640          STANDARD
2650 !
2660          LORG 5
2670          LDIR 0
2680          Inc=(Ymax-Ymin)*.21
2690 !
2700       ELSE
2710 Plot_thrust: ! X-AXIS FOR THRUST HISTOGRAMS
2720 !
2730          Inc=(Ymax-Ymin)*.02! PLACES TICKS ON X-AXIS
2740          FOR I=0 TO 32
2750             MOVE I,Ymax
2760             PLOT I,Ymax-Inc,-1
2770             MOVE I,Inc+Ymin
2780             PLOT I,Ymin,-1
2790             MOVE I,-Inc+Ymin
2800             LABEL USING "K";VAL$((I-16)*Cal)
2810          NEXT I
2820          STANDARD
2830 !
2840           .DIR 0
2850          Inc=(Ymax-Ymin)*.21
2860          LORG 2
2870          MOVE 0,Ymin-Inc
2880          LABEL USING "K";"-COMPRESSION-"!LABLES UNDER THRUST PLOT
2890          LORG 8
2900          MOVE 32,Ymin-Inc
2910          LABEL USING "K";"-TENSION-"
2920       END IF
2930   !
2940 X_end: ! END OF X-AXIS LABELING
2950   !
2960 Xvar:CSIZE 3
2970       LORG 5
2980       MOVE 16,Ymin-Inc
2990       LABEL USING "K";"BIN RANGES ("&Units$&")"
3000 !
3010 Ylabel:CSIZE 2.5
3020       LORG 8
3030       Inc=Xmax*.012
3040       IF NOT Scflag THEN
3050          IF Ymax>=0 THEN
3060             FOR Y=0 TO Ymax
3070                CALL Ylabel(Y,Inc,1)
3080             NEXT Y
3090          ELSE
3100 N_label:    FOR Y=0 TO Ymax-1
3110                CALL Ylabel(Y,Inc,0)
3120                CALL Ylabel(Y+LGT(2),Inc,0)
3130                CALL Ylabel(Y+LGT(5),Inc,0)
3140             NEXT Y
3150             CALL Ylabel(Ymax,Inc,0)
```

```
3160         END IF
3170  !
3180      ELSE
3190 Per_cent_label:FOR Y=LGT(.000001) TO Ymax
3200            CALL Ylabel(Y,Inc,1)
3210         NEXT Y
3220      END IF
3230 Axis_name:CSIZE 3
3240      LORG 5
3250      LDIR 90
3260      MOVE -Xmax*.1,(Ymax+Ymin)*.5! LABLES Y-AXIS
3270      IF NOT Scflag THEN
3280         IF Type$="C" THEN
3290            IF Counts=800 THEN
3300               LABEL USING "K";"COUNTS AT 800/SEC."
3310            ELSE
3320               LABEL USING "K";"COUNTS AT 2400/SEC."
3330            END IF
3340         ELSE
3350            LABEL USING "K";"LEVEL CROSSINGS"
3360         END IF
3370      ELSE
3380         IF Type$="C" THEN
3390            LABEL USING "K";"PER CENT COUNTS"
3400         ELSE
3410            LABEL USING "K";"PER CENT CROSSINGS"
3420         END IF
3430      END IF
3440 !
3450 Title:CSIZE 3.2
3460      LDIR 0
3470      Y=(Ymax-Ymin)*.1+Ymax
3480      MOVE Xmax*.25,Y
3490      LABEL USING "K";Name$
3500      MOVE Xmax*.75,Y
3510      LABEL USING "K";"RUN START: "&Date$
3520 !
3530 Plot:FOR I=1 TO 32
3540         IF Temp(I,Col)=0 THEN Nxti
3550         Y=LGT(Temp(I,Col))
3560         FOR X=I-1 TO I STEP .05
3570            MOVE X,Ymin
3580            PLOT X,Y,-1
3590         NEXT X
3600 Nxti:NEXT I
3610   SUBEND
3620 !
3630 File:    !
3640   SUB File(Nm$,Dt$,Tm$,Span$,Thk$,Units$,Cal,Temp(*))
3650      OPTION BASE 1
3660      INTEGER F1
3670 File_name: !
3680      INPUT "ENTER NAME OF HISTOGRAM DATA FILE INCLUDING DEVICE SPECIFIER",F
ile$
3690      F1=INT((5*(18+4)+30+4+8+8+32*2+8+12)/256)+1
3700 Create2:ON ERROR GOTO Service
3710      CREATE File$,F1
3720      OFF ERROR
3730      ASSIGN #1 TO File$
3740      PRINT #1;Nm$,Dt$,Tm$,Span$,Thk$,Units$
3750      PRINT #1;Cal
3760      PRINT #1;Temp(*)
3770      ASSIGN #1 TO *
3780      SUBEXIT
3790 !
3800 Service:IF ERRN<>54 THEN Message
```

```
3810       Inpt$=""
3820       INPUT "DUPLICATE FILE NAME: ENTER P TO PURGE OR CONT",Inpt$
3830       IF UPC$(Inpt$[1,1])<>"P" THEN File_name
3840       PURGE File$
3850       GOTO Create2
3860 Message:DISP ERRM$&" ENTER CONT TO RE-ENTER"
3870       PAUSE
3880       GOTO File_name
3890    SUBEND
3900 !
3910 Ylbl: !
3920    SUB Ylabel(Lg,Inc,INTEGER Iop)
3930       FIXED 0
3940       MOVE -Inc,Lg
3950       IF Iop=0 THEN LABEL USING "K";VAL$(10^Lg)
3960       IF Iop=1 THEN LABEL USING "K";"10^"&VAL$(Lg)
3970       IF Iop=2 THEN LABEL USING "DDD.DDDDD";10^Lg
3980       IF FRACT(Lg)<>0 THEN LINE TYPE 3
3990       MOVE 0,Lg
4000       PLOT 32,Lg,-1
4010       LINE TYPE 1
4020       STANDARD
4030    SUBEND
4040 !
4050 Table1:      !
4060    SUB Table1(Type$,Name$,Date$,Time$,Span$,Thickn$,Units$,Cal,Temp(*),INTEG
ER Scale_flag,INTEGER Lines,INTEGER Counts)
4070       OPTION BASE 1
4080       DIM Hdr1$[42],Hdr2$[42]
4090       IF Type$="C" THEN Col=1
4100       IF Type$="L" THEN Col=2
4110       Hdr1$="MV R LEMEUR PROPELLER BLADE TESTS"
4120       IF NOT Scale_flag THEN
4130          Hdr2$="DATAMYTE 400 RECORDED DATA"
4140       ELSE
4150          Hdr2$="DATAMYTE 400 LOAD HISTORY IN PER CENT"
4160       END IF
4170       PRINT TAB((80-LEN(Hdr1$))*.5),Hdr1$
4180       PRINT TAB((80-LEN(Hdr2$))*.5),Hdr2$
4190       PRINT
4200       PRINT TAB(15),"TIME AT LEVEL HISTOGRAM FOR "&Name$
4210       Days$=VAL$(VAL(Span$)/86400)
4220       PRINT TAB(15),"DATA COLLECTION BEGUN AT "&Time$&" ON "&Date$
4230       PRINT TAB(15),"ELAPSED TIME DURING DATA COLLECTION: "&Days$&" DAYS"
4240       NORMAL
4250       IF Thickn$<>"" THEN PRINT TAB(15),"ICE CONDITION DURING DATA COLLECTIO
N: "&Thickn$
4260       PRINT TAB(15),"CALIBRATION:";Cal;Units$&" / BIN"
4270       PRINT
4280       IF NOT Scale_flag THEN
4290          PRINT TAB(14);"BIN";TAB(29);"COUNT";TAB(58);"RANGE"
4300          PRINT TAB(55-LEN(Units$)*.5);"("&Units$&")"
4310          Lines=11
4320          FOR I=1 TO 32
4330             IF Temp(I,Col)=0 THEN Inc_i
4340             Lines=Lines+1
4350             IF POS(Name$,"TORQUE")<>0 THEN
4360                PRINT USING P_list2;I,Temp(I,Col),(I-1)*Cal,I*Cal
4370             ELSE
4380                PRINT USING P_list2;I,Temp(I,Col),(I-17)*Cal,(I-16)*Cal
4390             END IF
4400 P_list2:    IMAGE 13X,3D,4X,12D,10X,5D.1D,9X,5D.1D
4410 Inc_i:  NEXT I
4420       ELSE
4430 Scaled_table:  !
4440          PRINT TAB(14);"BIN";TAB(28);"PER CENT";TAB(58);"RANGE"
```

```
4450         PRINT TAB(55-LEN(Units$)*.5);"("&Units$&")"
4460         Lines=11
4470         FOR I=1 TO 32
4480            IF Temp(I,Col)=0 THEN Inc2_i
4490            Lines=Lines+1
4500            IF POS(Name$,"TORQUE")<>0 THEN
4510               PRINT USING P_list3;I,Temp(I,Col),(I-1)*Cal,I*Cal
4520            ELSE
4530               PRINT USING P_list3;I,Temp(I,Col),(I-17)*Cal,(I-16)*Cal
4540            END IF
4550 P_list3:   IMAGE 13X,3D,7X,3D.6D,9X,5D.1D,9X,5D.1D
4560 Inc2_i: NEXT I
4570      END IF
4580 End_table:SUBEND
4590 !
4600 Read2:     !
4610   SUB Read2(Nm$,Dt$,Tm$,Span$,Thk$,Units$,Cal,Temp(*))
4620      OPTION BASE 1
4630      INTEGER F1
4640      INPUT "ENTER NAME OF FILE FROM WHICH TO READ DATA",File$
4650      ASSIGN #1 TO File$
4660      BUFFER #1
4670      READ #1;Nm$,Dt$,Tm$,Span$,Thk$,Units$
4680      READ #1;Cal
4690      READ #1;Temp(*)
4700      ASSIGN #1 TO *
4710      SUBEXIT
4720   SUBEND
```

APPENDIX E

SHAFT STATISTICS HISTOGRAMS AND TABLES

SOURCE: CANMAR

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PERIOD #	START DATE	END DATE	DURATION OF TEST (DAYS)	DURATION OF SUCCESSFUL DATA COLLECTION (DAYS)				
				REAL TIME RAINFLOW			TIME AT LEVEL PLUS LEVEL CROSSINGS	
				THRUST HYS.=2	THRUST HYS.=3	TORQUE HYS.=2	THRUST HYS.=2	TORQUE HYS.=2
1	84-07-04	84-08-07	33.8	16.8	-	33.8	33.8	33.8
2	84-08-08	84-09-04	27.1	3.9	21.1	27.1	27.1	27.1
3	84-09-05	84-10-02	27.2	10.6	-	27.2	27.2	27.2
4	84-10-03	84-10-30	26.6	0.9	26.5	26.6	26.6	26.6
	TOTAL DAYS		114.7	32.2	47.6	114.7	114.7	114.7
	TOTAL AVAILABLE DAYS		117					

CANADIAN
MARINE
DRILLING
LIMITED

MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

TITLE:
LONG TERM SHAFT STATISTICS
DATAMYTE PERFORMANCE SUMMARY

TABLE No. 1

```
DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT THRUST
DATA COLLECTION BEGUN AT 22:20:00 ON 84/07/04
ELAPSED TIME DURING DATA COLLECTION: 16.7916666667 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
PHYSICAL DAMAGE LIMIT: 0 kN
CALIBRATION: 144 kN / BIN
HYSTERESIS: 2                      BIAS:  0

INDEX          RANGE           MEAN           COUNT
  1              3              -5              1
  2              3              -3              74
  3              3              -2              5122
  4              3              -1              65280
  5              3               0              21390
  6              3               1              826
  7              3               2              2205
  8              3               3              174
  9              4              -3              3
 10              4              -2              461
 11              4              -1              9095
 12              4               0              9345
 13              4               1              220
 14              4               2              9
 15              4               3              77
 16              4               4              2
 17              5              -3              30
 18              5              -2              1392
 19              5              -1              5220
 20              5               0              267
 21              5               1              2
 22              5               2              1
 23              5               3              1
 24              6              -3              1
 25              6              -2              193
 26              6              -1              1312
 27              6               0              597
 28              6               1              7
 29              7              -3              16
 30              7              -2              304
 31              7              -1              484
 32              7               0              6
 33              7               1              3
 34              8              -2              56
 35              8              -1              175
 36              8               0              11
 37              8               1              1
 38              9              -2              79
 39              9              -1              25
 40             10              -2              11
 41             10              -1              17
 42             10               1              1
 43             11              -2              5
 44             13              -3              1
```

THE LOWER LIMIT OF BIN ZERO IS
0 kN. THRUST PEAKS ARE PLOTTED
IN FIGURE 1A

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: THRUST TWO DIMENSIONAL REAL TIME RAINFLOW CYCLES FOR FIRST TEST PERIOD.
		TABLE No. 2

```
DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT THRUST
DATA COLLECTION BEGUN AT 12:36:00 ON 04/00/00
ELAPSED TIME DURING DATA COLLECTION: 3.91458333333 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
PHYSICAL DAMAGE LIMIT: 0 kN
CALIBRATION: 144 kN / BIN
HYSTERESIS: 2                  BIAS:  0

INDEX           RANGE           MEAN            COUNT
  1               3              -5             2
  2               3              -4             2
  3               3              -3             30
  4               3              -2             3672
  5               3              -1             65281
  6               3               0             10939
  7               3               1             2434
  8               3               2             2085
  9               3               3             599
 10               3               4             2
 11               4              -3             2
 12               4              -2             415
 13               4              -1             8055
 14               4               0             8374
 15               4               1             233
 16               4               2             17
 17               4               3             115
 18               4               4             7
 19               5              -3             87
 20               5              -2             1292
 21               5              -1             4700
 22               5               0             400
 23               5               1             7
 24               5               2             3
 25               5               3             1
 26               6              -3             13
 27               6              -2             309
 28               6              -1             1273
 29               6               0             531
 30               6               1             24
 31               7              -3             60
 32               7              -2             401
 33               7              -1             356
 34               7               0             27
 35               7               1             2
 36               8              -3             3
 37               8              -2             138
 38               8              -1             206
 39               8               0             43
 40               8               1             2
 41               9              -3             13
 42               9              -2             67
 43               9              -1             23
 44               9               0             14
 45               9               1             1
 46              10              -3             1
 47              10              -2             14
 48              10              -1             14
 49              10               0             5
 50              10               1             1
 51              11              -2             3
 52              11              -1             4
 53              12              -2             1
 54              12               0             1
 55              13              -2             2
 56              14              -2             1
```

THE LOWER LIMIT OF BIN ZERO IS
0 kN THRUST PEAKS ARE PLOTTED
IN FIGURE 1B

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: THRUST TWO DIMENSIONAL REAL TIME RAINFLOW CYCLES FOR SECOND TEST PERIOD**
		TABLE No. 3

```
DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT THRUST
DATA COLLECTION BEGUN AT 07:06:00 ON 84/09/05
ELAPSED TIME DURING DATA COLLECTION: 10.6159722222 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
PHYSICAL DAMAGE LIMIT: 0 kN
CALIBRATION: 144 kN / BIN
HYSTERESIS: 2                       BIAS:  0

INDEX          RANGE           MEAN          COUNT
  1              3              -3             6
  2              3              -2             512
  3              3              -1             40043
  4              3               0             65281
  5              3               1             6781
  6              3               2             4152
  7              3               3             256
  8              4              -2             42
  9              4              -1             1224
 10              4               0             6513
 11              4               1             1558
 12              4               2             54
 13              4               3             54
 14              5              -3             6
 15              5              -2             104
 16              5              -1             901
 17              5               0             548
 18              5               1             126
 19              5               3             1
 20              6              -2             10
 21              6              -1             116
 22              6               0             264
 23              6               1             115
 24              6               2             2
 25              7              -2             24
 26              7              -1             67
 27              7               0             44
 28              7               1             13
 29              8              -2             1
 30              8              -1             13
 31              8               0             33
 32              8               1             7
 33              9              -1             8
 34              9               0             8
 35             10              -1             1
 36             10               0             4
 37             11              -1             2
```

THE LOWER LIMIT OF BIN ZERO IS
0 kN THRUST PEAKS ARE PLOTTED
IN FIGURE 1C

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: THRUST TWO DIMENSIONAL REAL TIME RAINFLOW CYCLES FOR THIRD TEST PERIOD** **TABLE No. 4**

DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT THRUST
DATA COLLECTION BEGUN AT 10:15:00 ON 84:10:03
ELAPSED TIME DURING DATA COLLECTION: .897222222222 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
PHYSICAL DAMAGE LIMIT: 0 kN
CALIBRATION: 144 kN / BIN
HYSTERESIS: 2   BIAS: 0

INDEX	RANGE	MEAN	COUNT
1	3	-2	22
2	3	-1	4089
3	3	0	65281
4	3	1	2482
5	3	2	727
6	3	3	15
7	4	-2	2
8	4	-1	57
9	4	0	4709
10	4	1	1385
11	4	2	6
12	4	3	16
13	5	-2	1
14	5	-1	154
15	5	0	467
16	5	1	107
17	6	-1	6
18	6	0	114
19	6	1	34
20	6	2	4
21	7	-2	1
22	7	-1	12
23	7	0	39
24	7	1	2
25	8	-1	1
26	8	0	18
27	8	1	4
28	8	2	1
29	9	-1	2
30	9	0	3

THE LOWER LIMIT OF BIN ZERO IS
0 kN THRUST PEAKS ARE PLOTTED
IN FIGURE 1D

CANMAR

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: THRUST TWO DIMENSIONAL REAL TIME RAINFLOW CYCLES, FOURTH TEST PERIOD

TABLE No. 5

DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT THRUST
DATA COLLECTION BEGUN AT 12:30:00 ON 84/08/00
ELAPSED TIME DURING DATA COLLECTION: 21.0826300089 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
PHYSICAL DAMAGE LIMIT: 0 kN
CALIBRATION: 144 kN / BIN
HYSTERESIS: 3 BIAS: 0

INDEX	RANGE	MEAN	COUNT
1	4	-3	33
2	4	-2	5005
3	4	-1	65201
4	4	0	34970
5	4	1	1312
6	4	2	90
7	4	3	1160
8	4	4	83
9	4	5	16
10	5	-3	505
11	5	-2	10553
12	5	-1	25703
13	5	0	1527
14	5	1	63
15	5	2	27
16	5	3	45
17	5	4	15
18	5	5	1
19	6	-3	39
20	6	-2	1695
21	6	-1	8257
22	6	0	2507
23	6	1	164
24	6	2	6
25	6	3	1
26	6	4	1
27	6	5	6
28	7	-3	202
29	7	-2	1966
30	7	-1	2020
31	7	0	142
32	7	1	24
33	7	4	2
34	8	-3	4
35	8	-2	419
36	8	-1	792
37	8	0	251
38	8	1	16
39	9	-3	40
40	9	-2	256
41	9	-1	224
42	9	0	46
43	9	1	1
44	10	-3	1
45	10	-2	47
46	10	-1	87
47	10	0	64
48	10	1	4
49	11	-3	2
50	11	-2	20
51	11	-1	40
52	11	0	2
53	12	-2	2
54	12	-1	20
55	12	0	9
56	13	-2	4
57	13	-1	7
58	14	-1	7
59	15	-2	1

**THE LOWER LIMIT OF BIN ZERO IS
0 kN THRUST PEAKS ARE PLOTTED
IN FIGURE 2A**

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: THRUST TWO DIMENSIONAL REAL TIME RAINFLOW CYCLES FOR SECOND TEST PERIOD**
		TABLE No. 6

```
DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT THRUST
DATA COLLECTION BEGUN AT 10:13:00 ON 84:10:03
ELAPSED TIME DURING DATA COLLECTION: 26.4840277778 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
PHYSICAL DAMAGE LIMIT: 0 kN
CALIBRATION: 144 kN / BIN
HYSTERESIS: 3                 BIAS:  0

INDEX          RANGE          MEAN          COUNT
  1              4             -2            105
  2              4             -1            1023
  3              4              0            12813
  4              4              1            5932
  5              4              2            34
  6              4              3            424
  7              4              4            309
  8              4              5            3
  9              5             -2            246
 10              5             -1            778
 11              5              0            1619
 12              5              1            169
 13              5              2            2
 14              5              3            138
 15              5              4            16
 16              5              5            1
 17              6             -2            16
 18              6             -1            163
 19              6              0            225
 20              6              1            185
 21              6              2            10
 22              6              4            26
 23              7             -2            35
 24              7             -1            48
 25              7              0            51
 26              7              1            33
 27              8             -2            1
 28              8             -1            9
 29              8              0            21
 30              8              1            3
 31              8              3            1
 32              9             -2            2
 33              9             -1            7
 34              9              0            3
 35              9              1            1
 36             10             -1            1
 37             10              0            2
 38             10              3            1
 39             11             -1            1
 40             12             -1            1
 41             12              1            1
```

THE LOWER LIMIT OF BIN ZERO IS
0 kN THRUST PEAKS ARE PLOTTED
IN FIGURE 2B

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: THRUST TWO DIMENSIONAL REAL TIME RAINFLOW CYCLES FOR FOURTH TEST PERIOD** **TABLE No. 7**

```
DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT TORQUE
DATA COLLECTION BEGUN AT 22:22:00 ON 84/07/04
ELAPSED TIME DURING DATA COLLECTION: 33.0326388889 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
PHYSICAL DAMAGE LIMIT: 1367 kN.m
CALIBRATION: 17 kN.m / BIN
HYSTERESIS: 2                          BIAS:  0

INDEX          RANGE          MEAN          COUNT
  1              3             -14           5116
  2              3             -13           1760
  3              3             -12           2499
  4              3             -11           2770
  5              3             -10           6421
  6              3             -9            11770
  7              3             -8            9720
  8              3             -7            3895
  9              3             -6            1252
  10             3             -5            363
  11             3             -4            69
  12             3             -3            14
  13             3             -2            4
  14             3             -1            7
  15             4             -13           3887
  16             4             -12           1305
  17             4             -11           1504
  18             4             -10           1453
  19             4             -9            3042
  20             4             -8            4519
  21             4             -7            3660
  22             4             -6            1300
  23             4             -5            342
  24             4             -4            74
  25             4             -3            13
  26             4             -2            1
  27             4             -1            1
  28             4              0            1
  29             5             -13           1938
  30             5             -12           1100
  31             5             -11           985
  32             5             -10           960
  33             5             -9            1040
  34             5             -8            2856
  35             5             -7            1690
  36             5             -6            400
  37             5             -5            71
  38             5             -4            10
  39             5             -2            1
  40             5             -1            1
  41             6             -12           523
  42             6             -11           315
  43             6             -10           284
  44             6             -9            437
  45             6             -8            1059
  46             6             -7            1574
  47             6             -6            661
  48             6             -5            97
  49             6             -4            11
  50             6             -2            2
  51             6             -1            1
  52             7             -12           347
  53             7             -11           59
  54             7             -10           139
  55             7             -9            294
  56             7             -8            649
  57             7             -7            724
  58             7             -6            197
  59             7             -5            21
  60             7             -4            1
  61             7             -3            1
  62             8             -11           350
  63             8             -10           35
  64             8             -9            99
  65             8             -8            166
  66             8             -7            364
  67             8             -6            271
  68             8             -5            44
  69             8             -4            2
  70             8             -2            1
  71             9             -11           247
  72             9             -10           37
  73             9             -9            28
  74             9             -8            110
  75             9             -7            176
  76             9             -6            60
  77             9             -5            1
  78             10            -10           280
  79             10            -9            17
  80             10            -8            24
  81             10            -7            67
  82             10            -6            71
  83             10            -5            9
  84             11            -10           284
  85             11            -9            7
  86             11            -8            18
  87             11            -7            29
  88             11            -6            8
  89             11            -5            5
  90             12            -9            243
  91             12            -8            4
  92             12            -7            4
  93             12            -5            2
  94             13            -9            222
  95             13            -8            2
  96             13            -6            1
  97             14            -8            143
  98             15            -8            48
  99             16            -7            47
  100            17            -7            19
  101            18            -6            3
  102            31             0            8
```

THE LOWER LIMIT OF BIN ZERO IS 272 kN.m TORQUE PEAKS ARE PLOTTED IN FIGURE 3A

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: TORQUE TWO DIMENSIONAL REAL TIME RAINFLOW CYCLES FOR FIRST TEST PERIOD**
		TABLE No. 8

```
DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT TORQUE
DATA COLLECTION BEGUN AT 12:43:00 ON 04/08/88
ELAPSED TIME DURING DATA COLLECTION: 27.1326388889 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
PHYSICAL DAMAGE LIMIT: 1347 kN.m
CALIBRATION: 17 kN.m / BIN
HYSTERESIS: 2                   BIAS:  0

INDEX          RANGE          MEAN          COUNT
  1              3             -14           8864
  2              3             -13           1403
  3              3             -12           1122
  4              3             -11           995
  5              3             -10           2722
  6              3             -9            10663
  7              3             -8            24664
  8              3             -7            6381
  9              3             -6            2456
 10              3             -5            800
 11              3             -4            225
 12              3             -3            56
 13              3             -2            23
 14              3             -1            7
 15              4             -13           10434
 16              4             -12           1369
 17              4             -11           979
 18              4             -10           750
 19              4             -9            1463
 20              4             -8            4163
 21              4             -7            6157
 22              4             -6            1072
 23              4             -5            634
 24              4             -4            160
 25              4             -3            51
 26              4             -2            5
 27              4             -1            2
 28              4              0            1
 29              5             -13           4746
 30              5             -12           1071
 31              5             -11           801
 32              5             -10           509
 33              5             -9            1021
 34              5             -8            3123
 35              5             -7            3549
 36              5             -6            630
 37              5             -5            137
 38              5             -4            35
 39              5             -3            3
 40              5             -2            4

 41              6             -12           811
 42              6             -11           194
 43              6             -10           162
 44              6             -9            215
 45              6             -8            634
 46              6             -7            1848
 47              6             -6            1594
 48              6             -5            146
 49              6             -4            22
 50              6             -3            2
 51              6             -2            1
 52              7             -12           539
 53              7             -11           52
 54              7             -10           36
 55              7             -9            110
 56              7             -8            436
 57              7             -7            1007
 58              7             -6            436
 59              7             -5            15
 60              7             -4            3
 61              7             -3            2
 62              8             -11           449
 63              8             -10           31
 64              8             -9            30
 65              8             -8            75
 66              8             -7            315
 67              8             -6            313
 68              8             -5            80
 69              8             -4            2
 70              8             -3            3
 71              9             -11           377
 72              9             -10           16
 73              9             -9            30
 74              9             -8            46
 75              9             -7            100
 76              9             -6            151
 77              9             -5            5
 78             10             -10           264
 79             10             -9            21
 80             10             -8            20
 81             10             -7            47
 82             10             -6            81
 83             10             -5            29
 84             10             -4            3
 85             11             -10           349
 86             11             -9            20
 87             11             -8            12
 88             11             -7            26
 89             11             -6            15
 90             11             -5            12
 91             11             -4            1
 92             12             -9            339
 93             12             -8            6
 94             12             -7            5
 95             12             -6            5
 96             12             -5            9
 97             13             -9            353
 98             13             -8            2
 99             13             -7            2
100             13             -6            3
101             13             -5            2
102             14             -8            290
103             14             -6            1
104             14             -5            1
105             15             -8            110
106             16             -7            100
107             17             -7            27
108             18             -6            5
109             19             -6            2
110             21              0            0
```

THE LOWER LIMIT OF BIN ZERO IS
272 kN.m TORQUE PEAKS ARE
PLOTTED IN FIGURE 3B

CANMAR

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: TORQUE TWO DIMENSIONAL REAL TIME RAINFLOW CYCLES FOR SECOND TEST PERIOD

TABLE No. 9

```
DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT TORQUE
DATA COLLECTION BEGUN AT 07:10:00 ON 04/09/05
ELAPSED TIME DURING DATA COLLECTION: 27.2541666667 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
PHYSICAL DAMAGE LIMIT: 1347 kN.m
CALIBRATION: 17 kN.m / BIN
HYSTERESIS: 2                  BIAS:  0

INDEX          RANGE          MEAN          COUNT
  1              3             -14           14445
  2              3             -13           3660
  3              3             -12           2174
  4              3             -11           1022
  5              3             -10           713
  6              3             -9            1437
  7              3             -8            1253
  8              3             -7            133
  9              3             -6            42
  10             3             -5            24
  11             3             -4            2
  12             3             -3            1
  13             4             -13           17213
  14             4             -12           3009
  15             4             -11           2376
  16             4             -10           1043
  17             4             -9            630
  18             4             -8            694
  19             4             -7            773
  20             4             -6            42
  21             4             -5            14
  22             4             -4            3
  23             5             -13           6630
  24             5             -12           2869
  25             5             -11           1915
  26             5             -10           965
  27             5             -9            481
  28             5             -8            615
  29             5             -7            654
  30             5             -6            9
  31             5             -5            3
  32             6             -12           1282
  33             6             -11           533
  34             6             -10           364
  35             6             -9            183
  36             6             -8            140
  37             6             -7            274
  38             6             -6            90
  39             7             -12           385
  40             7             -11           40
  41             7             -10           20
  42             7             -9            22
  43             7             -8            41
  44             7             -7            60
  45             7             -6            3
  46             8             -11           437
  47             8             -10           21
  48             8             -9            17
  49             8             -8            15
  50             8             -7            17
  51             8             -6            7
  52             9             -11           253
  53             9             -10           26
  54             9             -9            3
  55             9             -8            8
  56             9             -7            9
  57             9             -6            1
  58             10            -10           200
  59             10            -9            19
  60             10            -8            5
  61             10            -7            2
  62             10            -6            1
  63             11            -10           176
  64             11            -9            5
  65             11            -8            1
  66             12            -9            102
  67             12            -8            2
  68             13            -9            23
  69             14            -8            14
  70             15            -8            3
  71             16            -7            2
  72             31             0            0
```

THE LOWER LIMIT OF BIN ZERO IS
272 kN.m TORQUE PEAKS ARE
PLOTTED IN FIGURE 3C

CANMAR **CANADIAN MARINE DRILLING LIMITED**	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: TORQUE TWO DIMENSIONAL REAL TIME RAINFLOW CYCLES FOR THIRD TEST PERIOD** **TABLE No. 10**

```
DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT TORQUE
DATA COLLECTION BEGUN AT 08:00:00 ON 84/10/03
ELAPSED TIME DURING DATA COLLECTION: 26.6034722222 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
PHYSICAL DAMAGE LIMIT: 1347 k.Nm
CALIBRATION: 17 k.Nm / BIN
HYSTERESIS: 2                       BIAS:  0

INDEX           RANGE           MEAN          COUNT
  1               3              -14           21570
  2               3              -13           1818
  3               3              -12           1719
  4               3              -11           1232
  5               3              -10           3920
  6               3              -9            27615
  7               3              -8            2535
  8               3              -7            183
  9               3              -6            36
  10              3              -5            13
  11              3              -4            1
  12              4              -13           23799
  13              4              -12           2004
  14              4              -11           1006
  15              4              -10           1054
  16              4              -9            2131
  17              4              -8            5716
  18              4              -7            731
  19              4              -6            31
  20              4              -5            8
  21              4              -4            3
  22              5              -13           4962
  23              5              -12           1750
  24              5              -11           1673
  25              5              -10           1319
  26              5              -9            1974
  27              5              -8            5400
  28              5              -7            304
  29              5              -6            9
  30              6              -12           722
  31              6              -11           427
  32              6              -10           272
  33              6              -9            462
  34              6              -8            1021
  35              6              -7            2915
  36              6              -6            9
  37              6              -5            2
  38              7              -12           252
  39              7              -11           38
  40              7              -10           29
  41              7              -9            132
  42              7              -8            335
  43              7              -7            79
  44              7              -6            1
  45              8              -11           288
  46              8              -10           6
  47              8              -9            11
  48              8              -8            38
  49              8              -7            54
  50              8              -6            6
  51              9              -11           135
  52              9              -10           20
  53              9              -9            11
  54              9              -8            14
  55              9              -7            8
  56              9              -6            2
  57              10             -10           124
  58              10             -9            15
  59              10             -8            7
  60              10             -7            1
  61              10             -6            1
  62              11             -10           163
  63              11             -9            2
  64              12             -9            75
  65              13             -9            22
  66              14             -8            8
  67              15             -8            4
  68              16             -7            2
  69              31              0            0
```

THE LOWER LIMIT OF BIN ZERO IS 272 kN.m TORQUE PEAKS ARE PLOTTED IN FIGURE 3D

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: TORQUE TWO DIMENSIONAL REAL TIME RAINFLOW CYCLES, FOR FOURTH TEST PERIOD**
		TABLE No. 11

```
               DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT THRUST
               DATA COLLECTION BEGUN AT 22:20:00 ON 84/07/04
               ELAPSED TIME DURING DATA COLLECTION:  33.781  DAYS
               ICE CONDITION DURING DATA COLLECTION: ASSORTED
               CALIBRATION: 144 kN / BIN

INDEX       COUNTS AT      PER CENT      LEVEL     PER CENT OF           RANGE
NUMB.       2400/SEC.     OF COUNTS    CROSSINGS LEVEL CROSSINGS         ( kN )
  1                0       0.000000            0        0.000000     -2304    -2160
  2                0       0.000000            0        0.000000     -2160    -2016
  3                0       0.000000            0        0.000000     -2016    -1872
  4                0       0.000000            0        0.000000     -1872    -1728
  5                0       0.000000            0        0.000000     -1728    -1584
  6                0       0.000000            0        0.000000     -1584    -1440
  7                1        .000000            1         .000000     -1440    -1296
  8                4        .000000            4         .000002     -1296    -1152
  9               81        .000001           61         .000027     -1152    -1008
 10             1661        .000024          793         .000357     -1008     -864
 11            12392        .000177         5255         .002366      -864     -720
 12            99672        .001421        35405         .015943      -720     -576
 13           825141        .011760       260455         .117285      -576     -432
 14          9735748        .138753      2921902        1.315754      -432     -288
 15        405365649       5.777221     88973077       40.065229      -288     -144
 16       2152392779      30.675634     22278185       10.032030      -144        0
 17       3396501046      48.406511     18686535        8.414684         0      144
 18       1035488596      14.757655     85488692       38.496184       144      288
 19         15319293        .218329      3108666        1.399855       288      432
 20           862135        .012287       305103         .137390       432      576
 21            15961        .000227         6365         .002866       576      720
 22              100        .000001           60         .000027       720      864
 23                0       0.000000            0        0.000000       864     1008
 24                0       0.000000            0        0.000000      1008     1152
 25                0       0.000000            0        0.000000      1152     1296
 26                0       0.000000            0        0.000000      1296     1440
 27                0       0.000000            0        0.000000      1440     1584
 28                0       0.000000            0        0.000000      1584     1728
 29                0       0.000000            0        0.000000      1728     1872
 30                0       0.000000            0        0.000000      1872     2016
 31                0       0.000000            0        0.000000      2016     2160
 32                0       0.000000            0        0.000000      2160     2304
```

PERCENT OF COUNTS PLOTTED IN FIGURE 4A, PERCENT OF LEVEL CROSSINGS PLOTTED IN FIGURE 5A, HYSTERESIS = 2

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **THRUST TIME AT LEVEL PLUS LEVEL CROSSING COUNTS FOR FIRST TEST PERIOD** **TABLE No. 12**

```
                  DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT THRUST
                  DATA COLLECTION BEGUN AT 12:30:00 ON 84/08/08
                  ELAPSED TIME DURING DATA COLLECTION:  27.103  DAYS
                  ICE CONDITION DURING DATA COLLECTION: ASSORTED
                  CALIBRATION: 144 kN / BIN

 INDEX       COUNTS AT      PER CENT       LEVEL     PER CENT OF            RANGE
 NUMB.      2400/SEC.      OF COUNTS   CROSSINGS LEVEL CROSSINGS           ( kN )
     1              0       0.000000           0       0.000000     -2304     -2160
     2              0       0.000000           0       0.000000     -2160     -2016
     3              0       0.000000           0       0.000000     -2016     -1872
     4              0       0.000000           0       0.000000     -1872     -1728
     5              0       0.000000           0       0.000000     -1728     -1584
     6              0       0.000000           0       0.000000     -1584     -1440
     7              5        .000000           3        .000002     -1440     -1296
     8             38        .000001          23        .000014     -1296     -1152
     9            459        .000008         276        .000169     -1152     -1008
    10           6039        .000107        2769        .001696     -1008      -864
    11          39220        .000697       16595        .016164      -864      -720
    12         271684        .004826       95773        .058660      -720      -576
    13        1979954        .035172      619852        .379650      -576      -432
    14       20590115        .365767     6541838       4.006779      -432      -288
    15      579594048      10.296017     5861167       3.589878      -288      -144
    16     1667043885      29.613680    22193587      13.593243      -144         0
    17     2206257324      39.192368    67648148      41.433489         0       144
    18     1103681971      19.606013    51300963      31.421080       144       288
    19       44935342        .798240     7452601       4.564608       288       432
    20        4782192        .084952     1488075        .911424       432       576
    21         116160        .002063       46061        .028212       576       720
    22           4179        .000074        1334        .000817       720       864
    23            753        .000013         164        .000100       864      1008
    24             50        .000001          26        .000016      1008      1152
    25              0       0.000000           0       0.000000      1152      1296
    26              0       0.000000           0       0.000000      1296      1440
    27              0       0.000000           0       0.000000      1440      1584
    28              0       0.000000           0       0.000000      1584      1728
    29              0       0.000000           0       0.000000      1728      1872
    30              0       0.000000           0       0.000000      1872      2016
    31              0       0.000000           0       0.000000      2016      2160
    32              0       0.000000           0       0.000000      2160      2304
```

PERCENT OF COUNTS PLOTTED IN FIGURE 4A, PERCENT OF LEVEL CROSSINGS PLOTTED IN FIGURE 5B, HYSTERESIS = 2

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **THRUST TIME AT LEVEL PLUS LEVEL CROSSING COUNTS, FOR SECOND TEST PERIOD** **TABLE No. 13**

DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT THRUST
DATA COLLECTION BEGUN AT 07:05:00 ON 84/09/05
ELAPSED TIME DURING DATA COLLECTION: 27.222 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
CALIBRATION: 144 kN / BIN

INDEX NUMB.	COUNTS AT 2400/SEC.	PER CENT OF COUNTS	LEVEL CROSSINGS	PER CENT OF LEVEL CROSSINGS	RANGE (kN)	
1	0	0.000000	0	0.000000	-2304	-2160
2	0	0.000000	0	0.000000	-2160	-2016
3	0	0.000000	0	0.000000	-2016	-1872
4	0	0.000000	0	0.000000	-1872	-1728
5	0	0.000000	0	0.000000	-1728	-1584
6	0	0.000000	0	0.000000	-1584	-1440
7	0	0.000000	0	0.000000	-1440	-1296
8	0	0.000000	0	0.000000	-1296	-1152
9	0	0.000000	0	0.000000	-1152	-1008
10	17	.000000	5	.000003	-1008	-864
11	309	.000005	143	.000072	-864	-720
12	3324	.000059	1135	.000569	-720	-576
13	30518	.000540	10590	.005305	-576	-432
14	558831	.009884	253934	.127196	-432	-288
15	89948458	1.590875	24040563	12.041992	-288	-144
16	891614260	15.769548	17347156	8.689244	-144	0
17	4014525278	71.002956	72413160	36.271974	0	144
18	639002555	11.301727	81722643	40.935123	144	288
19	16571787	.293097	3330129	1.668072	288	432
20	1742646	.030821	501386	.251146	432	576
21	27552	.000487	18549	.009291	576	720
22	29	.000001	29	.000015	720	864
23	0	0.000000	0	0.000000	864	1008
24	0	0.000000	0	0.000000	1008	1152
25	0	0.000000	0	0.000000	1152	1296
26	0	0.000000	0	0.000000	1296	1440
27	0	0.000000	0	0.000000	1440	1584
28	0	0.000000	0	0.000000	1584	1728
29	0	0.000000	0	0.000000	1728	1872
30	0	0.000000	0	0.000000	1872	2016
31	0	0.000000	0	0.000000	2016	2160
32	0	0.000000	0	0.000000	2160	2304

PERCENT OF COUNTS PLOTTED IN FIGURE 4C, PERCENT OF LEVEL CROSSINGS PLOTTED IN FIGURE 5C, HYSTERESIS = 2

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: THRUST TIME AT LEVEL PLUS LEVEL CROSSING COUNTS, FOR THIRD TEST PERIOD
		TABLE No. 14

```
          DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT THRUST
          DATA COLLECTION BEGUN AT 10:14:00 ON 84/10/03
          ELAPSED TIME DURING DATA COLLECTION:  26.572  DAYS
          ICE CONDITION DURING DATA COLLECTION: ASSORTED
          CALIBRATION: 144 kN / BIN

INDEX     COUNTS AT    PER CENT      LEVEL     PER CENT OF          RANGE
NUMB.    2400/SEC.   OF COUNTS  CROSSINGS LEVEL CROSSINGS         ( kN )
    1            0    0.000000          0        0.000000     -2304    -2160
    2            0    0.000000          0        0.000000     -2160    -2016
    3            0    0.000000          0        0.000000     -2016    -1872
    4            0    0.000000          0        0.000000     -1872    -1728
    5            0    0.000000          0        0.000000     -1728    -1584
    6            0    0.000000          0        0.000000     -1584    -1440
    7            0    0.000000          0        0.000000     -1440    -1296
    8            0    0.000000          0        0.000000     -1296    -1152
    9            0    0.000000          0        0.000000     -1152    -1008
   10           15     .000000          9         .000005     -1008     -864
   11          380     .000007        183         .000099      -864     -720
   12         6534     .000118       2364         .001276      -720     -576
   13        67722     .001227      21666         .011694      -576     -432
   14       751051     .013608     230865         .124609      -432     -288
   15    156605486    2.837514   57684121       31.134894      -288     -144
   16   1663209926   30.135475     756005         .408052      -144        0
   17   2528990229   45.822431   77912149       42.052934         0      144
   18   1136555214   20.593090   40734087       21.986146       144      288
   19     28779311     .521448    6839090        3.691386       288      432
   20      3965516     .071851    1036484         .559440       432      576
   21       167605     .003037      50748         .027391       576      720
   22        10255     .000186       3644         .001967       720      864
   23          456     .000008        193         .000104       864     1008
   24           17     .000000          6         .000003      1008     1152
   25            0    0.000000          0        0.000000      1152     1296
   26            0    0.000000          0        0.000000      1296     1440
   27            0    0.000000          0        0.000000      1440     1584
   28            0    0.000000          0        0.000000      1584     1728
   29            0    0.000000          0        0.000000      1728     1872
   30            0    0.000000          0        0.000000      1872     2016
   31            0    0.000000          0        0.000000      2016     2160
   32            0    0.000000          0        0.000000      2160     2304
```

PERCENT OF COUNTS PLOTTED IN FIGURE 4D, PERCENT OF LEVEL CROSSINGS PLOTTED IN FIGURE 5D, HYSTERESIS = 2

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: THRUST TIME AT LEVEL PLUS LEVEL CROSSING COUNTS, FOR FOURTH TEST PERIOD TABLE No. 15

```
DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT TORQUE
DATA COLLECTION BEGUN AT 22:21:00 ON 84/07/04
ELAPSED TIME DURING DATA COLLECTION:  33.783  DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
CALIBRATION: 17 kN.m / BIN
```

INDEX NUMB.	COUNTS AT 800/SEC.	PER CENT OF COUNTS	LEVEL CROSSINGS	PER CENT OF LEVEL CROSSINGS	RANGE (kN.m)	
1	1069727301	45.734198	7134	1.283846	0	17
2	220054593	9.408024	16531	2.974946	17	34
3	166906639	7.135782	22095	3.976252	34	51
4	165509912	7.076068	27923	5.025069	51	68
5	121984280	5.215211	36452	6.559961	68	85
6	137349138	5.872107	55784	10.038980	85	102
7	172292218	7.366033	81465	14.660574	102	119
8	208352752	8.907734	94818	17.063602	119	136
9	68201550	2.915830	86032	15.482459	136	153
10	6560228	.280470	62123	11.179756	153	170
11	1382820	.059120	36539	6.575618	170	187
12	465788	.019914	17942	3.228872	187	204
13	161261	.006894	7333	1.319659	204	221
14	46936	.002007	2505	.450804	221	238
15	11237	.000480	730	.131372	238	255
16	2225	.000095	190	.034193	255	272
17	616	.000026	58	.010438	272	289
18	127	.000005	17	.003059	289	306
19	19	.000001	3	.000540	306	323
20	0	0.000000	0	0.000000	323	340
21	0	0.000000	0	0.000000	340	357
22	0	0.000000	0	0.000000	357	374
23	0	0.000000	0	0.000000	374	391
24	0	0.000000	0	0.000000	391	408
25	0	0.000000	0	0.000000	408	425
26	0	0.000000	0	0.000000	425	442
27	0	0.000000	0	0.000000	442	459
28	0	0.000000	0	0.000000	459	476
29	0	0.000000	0	0.000000	476	493
30	0	0.000000	0	0.000000	493	510
31	0	0.000000	0	0.000000	510	527
32	0	0.000000	0	0.000000	527	544

PERCENT OF COUNTS ARE PLOTTED IN FIGURE 6A, PERCENT OF LEVEL CROSSINGS ARE PLOTTED IN FIGURE 7A, HYSTERESIS = 2

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **TORQUE TIME AT LEVEL PLUS LEVEL CROSSINGS FOR FIRST TEST PERIOD**
		TABLE No. 16

DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT TORQUE
DATA COLLECTION BEGUN AT 12:39:00 ON 84/08/08
ELAPSED TIME DURING DATA COLLECTION: 27.097 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
CALIBRATION: 17 kN.m / BIN

INDEX NUMB.	COUNTS AT 800/SEC.	PER CENT OF COUNTS	LEVEL CROSSINGS	PER CENT OF LEVEL CROSSINGS	RANGE (kN.m)	
1	803772812	42.843336	10441	1.727736	0	17
2	121963651	6.501003	24467	4.048703	17	34
3	74944446	3.994748	29513	4.883695	34	51
4	69259857	3.691744	29844	4.938468	51	68
5	60486013	3.224073	27757	4.593119	68	85
6	83275789	4.438832	35076	5.804239	85	102
7	140077231	7.466508	65005	10.756772	102	119
8	275564355	14.688350	96572	15.980355	119	136
9	233441062	12.443061	102781	17.007796	136	153
10	10324198	.550309	83265	13.778365	153	170
11	1922928	.102497	52495	8.686666	170	187
12	687843	.036664	27702	4.584018	187	204
13	250587	.013357	12458	2.061501	204	221
14	76664	.004086	4742	.784688	221	238
15	20897	.001114	1596	.264100	238	255
16	4744	.000253	465	.076946	255	272
17	955	.000051	109	.018037	272	289
18	204	.000011	24	.003971	289	306
19	45	.000002	4	.000662	306	323
20	2	.000000	1	.000165	323	340
21	0	0.000000	0	0.000000	340	357
22	0	0.000000	0	0.000000	357	374
23	0	0.000000	0	0.000000	374	391
24	0	0.000000	0	0.000000	391	408
25	0	0.000000	0	0.000000	408	425
26	0	0.000000	0	0.000000	425	442
27	0	0.000000	0	0.000000	442	459
28	0	0.000000	0	0.000000	459	476
29	0	0.000000	0	0.000000	476	493
30	0	0.000000	0	0.000000	493	510
31	0	0.000000	0	0.000000	510	527
32	0	0.000000	0	0.000000	527	544
	0	0.000000	0	0.000000		

PERCENT OF COUNTS ARE PLOTTED IN FIGURE 6B, PERCENT OF LEVEL CROSSINGS ARE PLOTTED IN FIGURE 7B, HYSTERESIS = 2

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: TORQUE TIME AT LEVEL PLUS LEVEL CROSSINGS FOR SECOND TEST PERIOD
		TABLE No. 17

```
DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT TORQUE
DATA COLLECTION BEGUN AT 07:08:00 ON 84/09/05
ELAPSED TIME DURING DATA COLLECTION:  27.217  DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
CALIBRATION: 17 kN.m / BIN

INDEX     COUNTS AT     PER CENT      LEVEL     PER CENT OF          RANGE
NUMB.     800/SEC.     OF COUNTS    CROSSINGS LEVEL CROSSINGS      ( kN.m )
  1      1346820845    71.471600       12991       5.696883        0      17
  2       104359694     5.538045       31574      13.845999       17      34
  3        89818688     4.766399       39993      17.537943       34      51
  4        80743683     4.284817       40511      17.765100       51      68
  5        55367587     2.938186       31909      13.992905       68      85
  6        40986695     2.175037       21801       9.560291       85     102
  7        46633458     2.474693       16414       7.197955      102     119
  8        88650889     4.704427       12977       5.690743      119     136
  9        30766105     1.632662        9309       4.082232      136     153
 10          182200      .009669        5735       2.514943      153     170
 11           56579      .003002        2975       1.304613      170     187
 12           19814      .001051        1321        .579292      187     204
 13            6080      .000323         400        .175410      204     221
 14            1309      .000069          93        .040783      221     238
 15             357      .000019          27        .011840      238     255
 16              35      .000002           7        .003070      255     272
 17               0     0.000000           0       0.000000      272     289
 18               0     0.000000           0       0.000000      289     306
 19               0     0.000000           0       0.000000      306     323
 20               0     0.000000           0       0.000000      323     340
 21               0     0.000000           0       0.000000      340     357
 22               0     0.000000           0       0.000000      357     374
 23               0     0.000000           0       0.000000      374     391
 24               0     0.000000           0       0.000000      391     408
 25               0     0.000000           0       0.000000      408     425
 26               0     0.000000           0       0.000000      425     442
 27               0     0.000000           0       0.000000      442     459
 28               0     0.000000           0       0.000000      459     476
 29               0     0.000000           0       0.000000      476     493
 30               0     0.000000           0       0.000000      493     510
 31               0     0.000000           0       0.000000      510     527
 32               0     0.000000           0       0.000000      527     544
```

PERCENT OF COUNTS ARE PLOTTED IN FIGURE 6C, PERCENT OF LEVEL CROSSINGS ARE PLOTTED IN FIGURE 7C, HYSTERESIS = 2

CANMAR **CANADIAN MARINE DRILLING LIMITED**	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **TORQUE TIME AT LEVEL PLUS LEVEL CROSSINGS FOR THIRD TEST PERIOD** **TABLE No. 18**

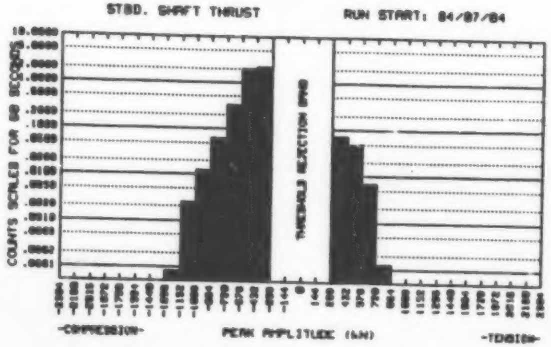
DATAMYTE 400 HISTOGRAM FOR STBD. SHAFT TORQUE
DATA COLLECTION BEGUN AT 07:59:00 ON 84/10/03
ELAPSED TIME DURING DATA COLLECTION: 26.567 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
CALIBRATION: 17 kN.m / BIN

INDEX NUMB.	COUNTS AT 800/SEC.	PER CENT OF COUNTS	LEVEL CROSSINGS	PER CENT OF LEVEL CROSSINGS	RANGE (kN.m)	
1	768739722	41.793753	18534	4.623917	0	17
2	69865171	3.798331	39976	9.973330	17	34
3	42585064	2.315204	45041	11.236961	34	51
4	54999124	2.990114	42415	10.581819	51	68
5	56603993	3.077366	31050	7.746445	68	85
6	137916043	7.498024	38783	9.675697	85	102
7	335966594	18.265356	56765	14.161899	102	119
8	356369107	19.374571	57890	14.442568	119	136
9	15919588	.865494	41150	10.266223	136	153
10	327247	.017791	18868	4.707244	153	170
11	52975	.002880	7541	1.881351	170	187
12	15377	.000836	2417	.603000	187	204
13	4245	.000231	319	.079585	204	221
14	794	.000043	61	.015218	221	238
15	92	.000005	15	.003742	238	255
16	22	.000001	4	.000998	255	272
17	0	0.000000	0	0.000000	272	289
18	0	0.000000	0	0.000000	289	306
19	0	0.000000	0	0.000000	306	323
20	0	0.000000	0	0.000000	323	340
21	0	0.000000	0	0.000000	340	357
22	0	0.000000	0	0.000000	357	374
23	0	0.000000	0	0.000000	374	391
24	0	0.000000	0	0.000000	391	408
25	0	0.000000	0	0.000000	408	425
26	0	0.000000	0	0.000000	425	442
27	0	0.000000	0	0.000000	442	459
28	0	0.000000	0	0.000000	459	476
29	0	0.000000	0	0.000000	476	493
30	0	0.000000	0	0.000000	493	510
31	0	0.000000	0	0.000000	510	527
32	0	0.000000	0	0.000000	527	544

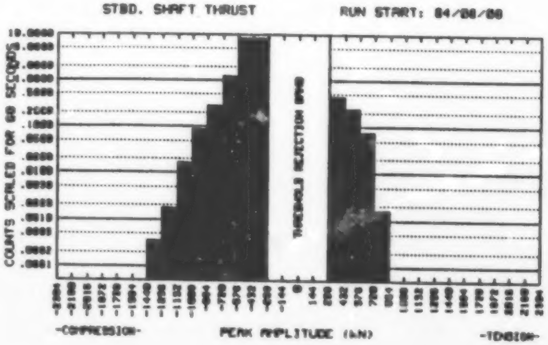
PERCENT OF COUNTS ARE PLOTTED IN FIGURE 6D, PERCENT OF LEVEL CROSSINGS ARE PLOTTED IN FIGURE 7D, HYSTERESIS = 2

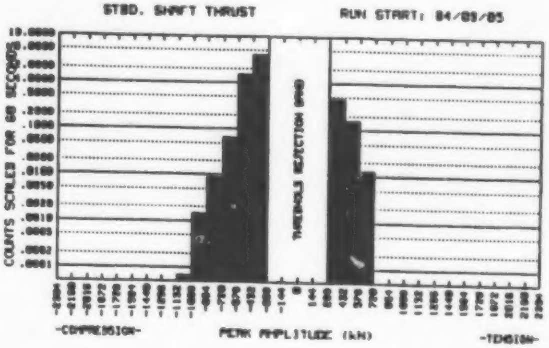
CANMAR **CANADIAN MARINE DRILLING LIMITED**	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **TORQUE TIME AT LEVEL PLUS LEVEL CROSSINGS, FOR FOURTH TEST PERIOD** **TABLE No. 19**

A
RAW DATA IS LISTED IN TABLE 2

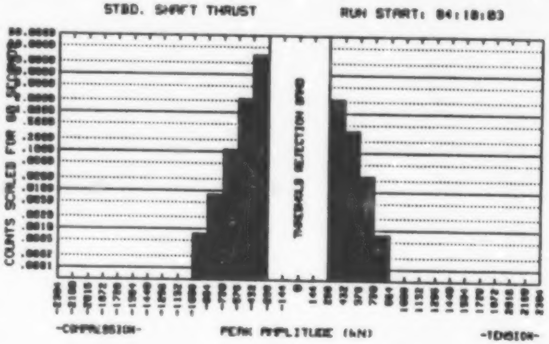


B
RAW DATA IS LISTED IN TABLE 3





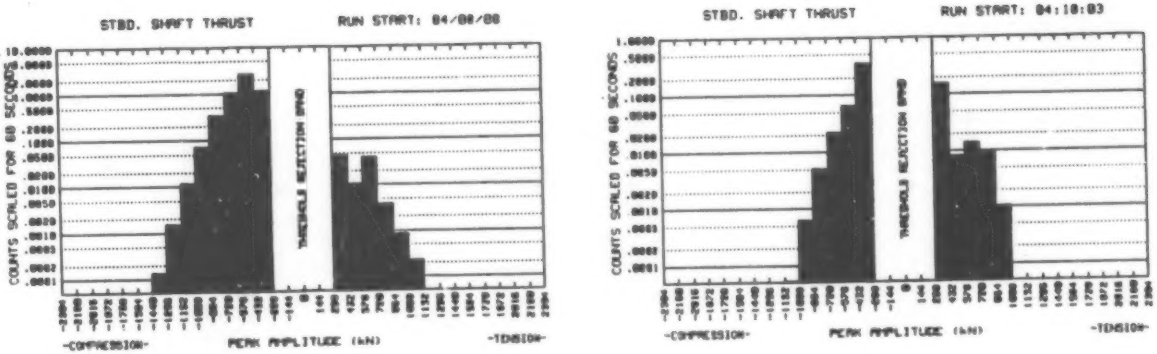
C
RAW DATA IS LISTED IN TABLE 4



D
RAW DATA IS LISTED IN TABLE 5

HYSTERESIS = 2

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: THRUST PEAKS PER MINUTE, FOR THE FOUR TEST PERIODS FIGURE No. 1



A
RAW DATA IS LISTED IN
TABLE 6

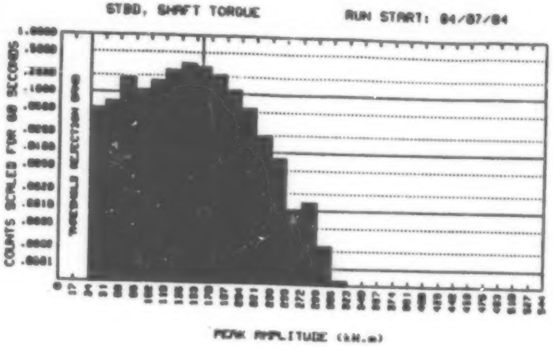
B
RAW DATA IS LISTED IN
TABLE 7

HYSTERESIS = 3

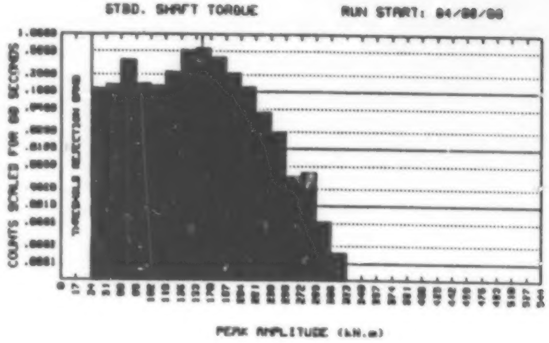
CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: THRUST PEAKS PER MINUTE, FOR TEST PERIOD NUMBERS TWO AND FOUR FIGURE No. 2

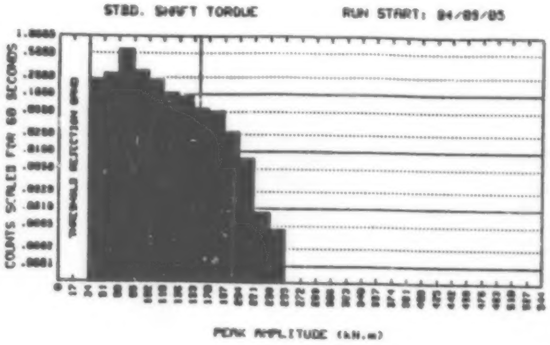
A

RAW DATA IS LISTED IN
TABLE 8

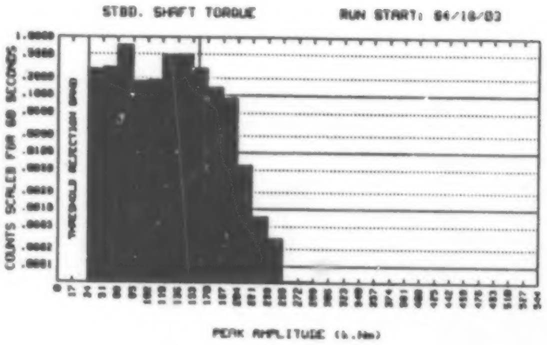


RAW DATA IS LISTED IN
TABLE 9





RAW DATA IS LISTED IN
TABLE 10

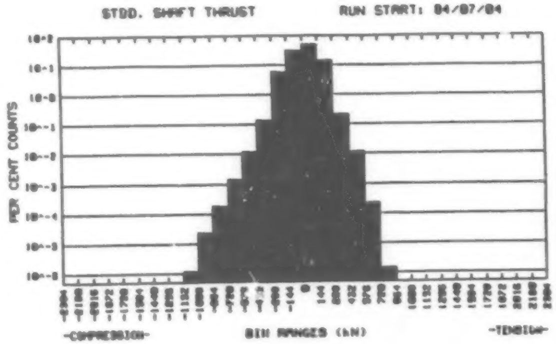


RAW DATA IS LISTED IN
TABLE 11

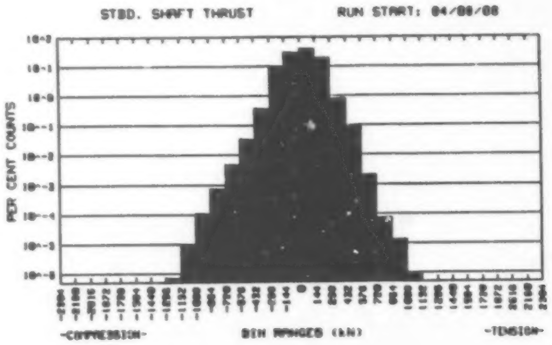
HYSTERESIS = 2

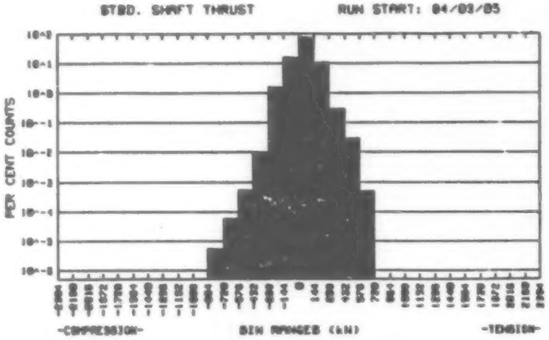
CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: TORQUE PEAKS PER MINUTE, FOR THE FOUR TEST PERIODS FIGURE No. 3

A
BIN READINGS ARE LISTED IN
TABLE 12

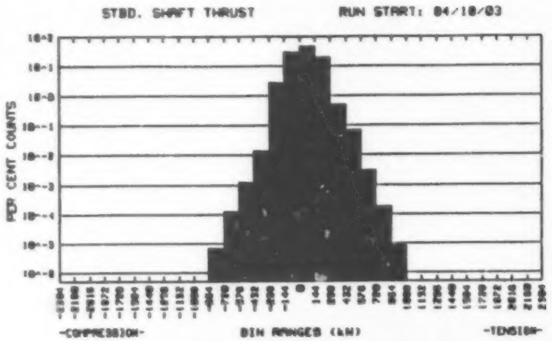


B
BIN READINGS ARE LISTED IN
TABLE 13





C
BIN READINGS ARE LISTED IN
TABLE 14



D
BIN READINGS ARE LISTED IN
TABLE 15

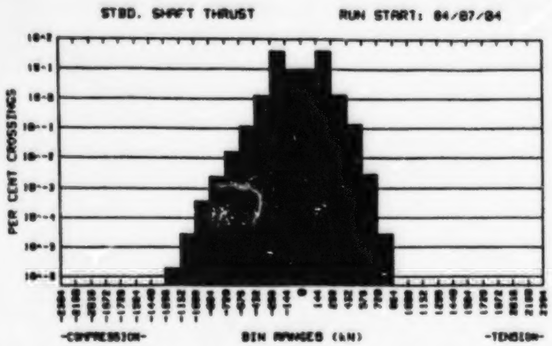
CANADIAN
MARINE
DRILLING
LIMITED

MEASUREMENT OF ICE
PROPELLER INTERACTION
PARAMETERS

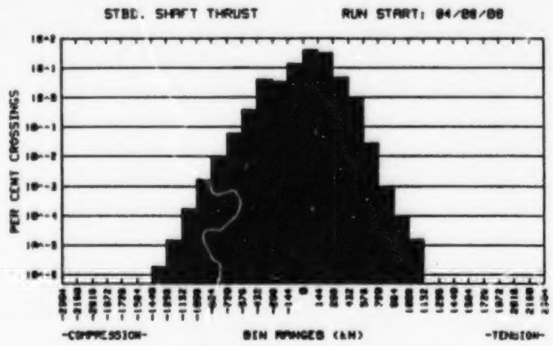
TITLE: THRUST PERCENT TIME AT LEVEL, FOR THE FOUR TEST PERIODS

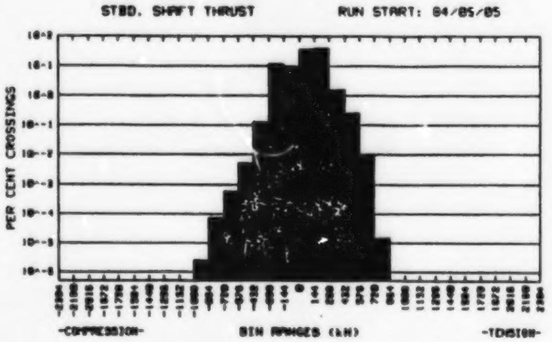
FIGURE No. 4

A
BIN READINGS ARE LISTED IN
TABLE 12

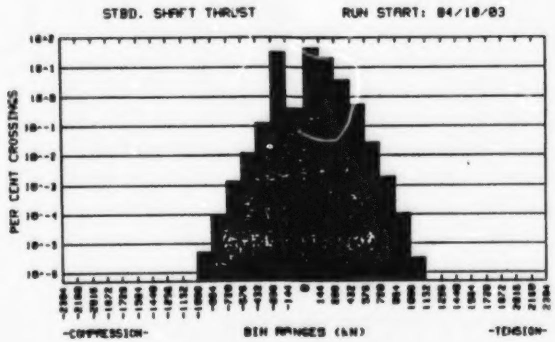


B
BIN READINGS ARE LISTED IN
TABLE 13





C
BIN READINGS ARE LISTED IN
TABLE 14

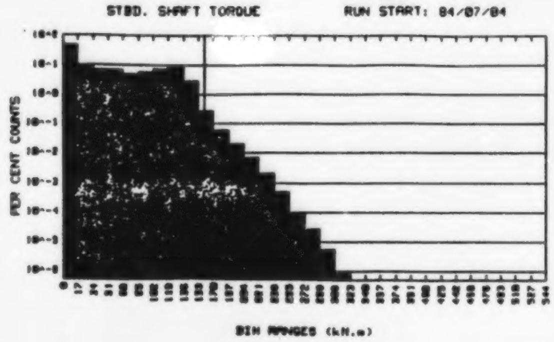


D
BIN READINGS ARE LISTED IN
TABLE 15

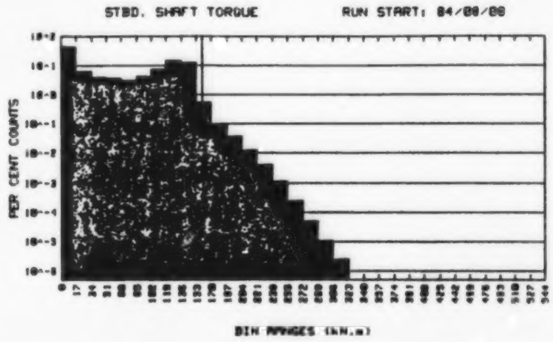
HYSTERESIS = 2

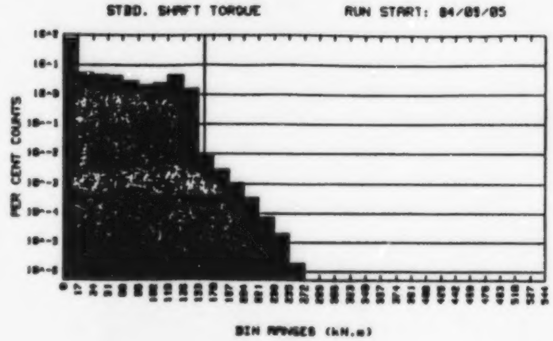
CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: THRUST PERCENT LEVEL CROSSINGS, FOR THE FOUR TEST PERIODS FIGURE No. 5

A
BIN READINGS ARE LISTED IN
TABLE 16

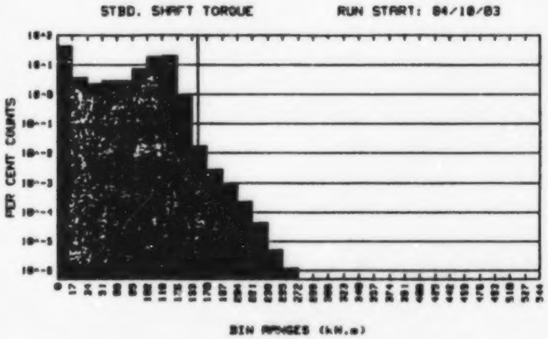


B
BIN READINGS ARE LISTED IN
TABLE 17





C
BIN READINGS ARE LISTED IN
TABLE 18

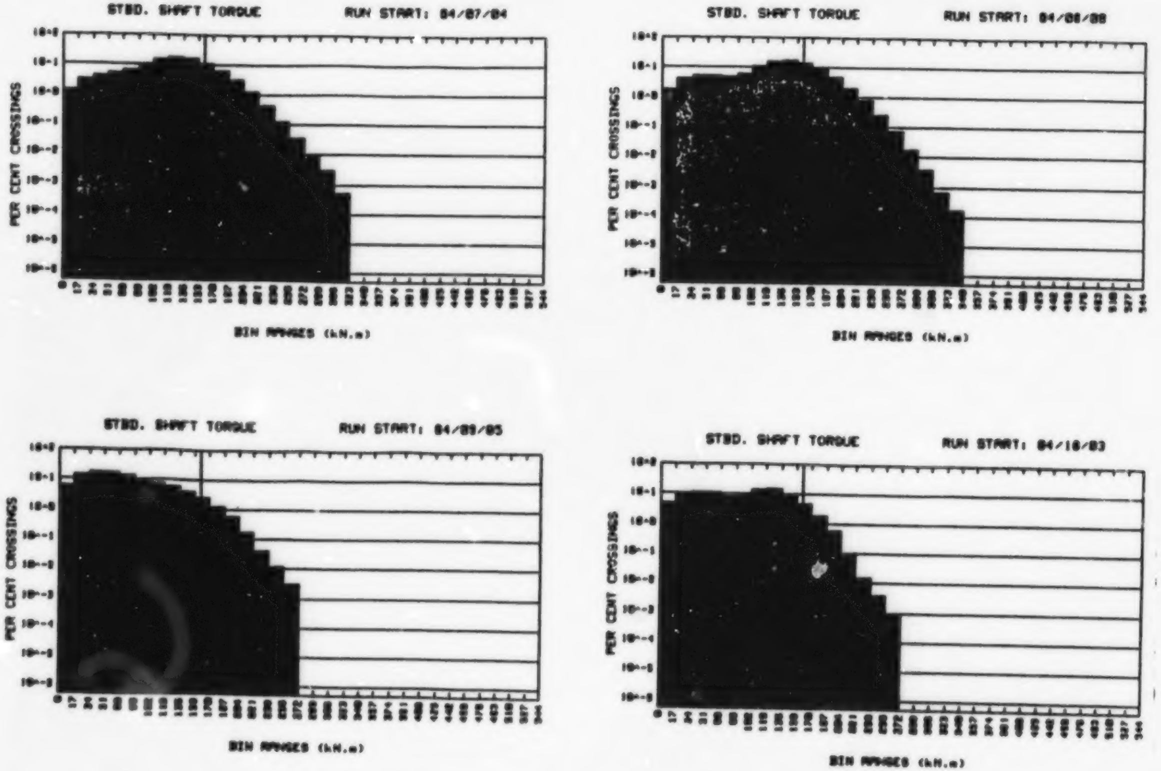


D
BIN READINGS ARE LISTED IN
TABLE 19

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: TORQUE PERCENT TIME AT LEVEL, FOR THE FOUR TEST PERIODS FIGURE No. 6

A
BIN READINGS ARE LISTED IN TABLE 16

B
BIN READINGS ARE LISTED IN TABLE 17



C
BIN READINGS ARE LISTED IN TABLE 18

D
BIN READINGS ARE LISTED IN TABLE 19

HYSTERESIS = 2

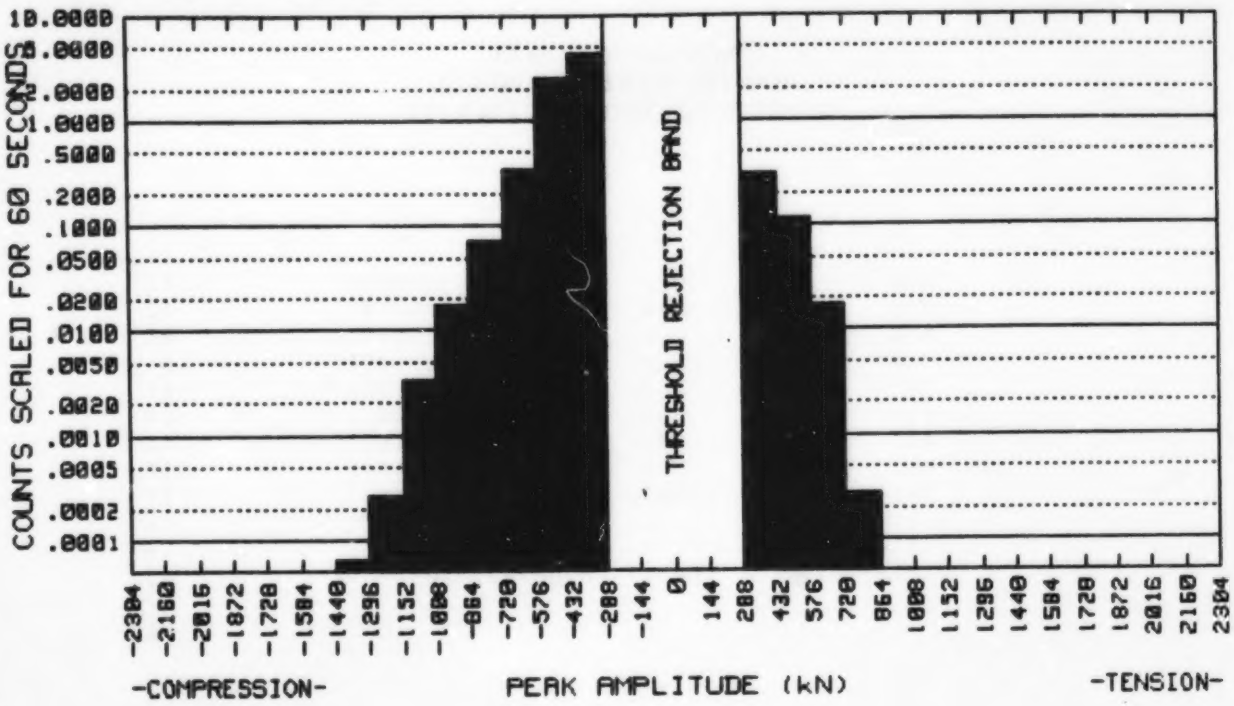
CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: TORQUE PERCENT LEVEL CROSSINGS, FOR THE FOUR TEST PERIODS FIGURE No. 7

```
                MV R LEMEUR PROPELLER BLADE TESTS
                    DATAMYTE 400 SCALED DATA

AMPLITUDE-FREQUENCY HISTOGRAM FOR SUM OF ALL THRUST #5 DATAMYTES
BASED UPON DATA COLLECTION BEGUN AT 22:20:00 ON 84/07/04
ELAPSED TIME DURING DATA COLLECTION: 32.2194444444 DAYS
DATA SCALED FOR 60 SECONDS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
CALIBRATION: 144 kN / BIN
HYSTERESIS: 2                BIAS:  0

BIN          COUNT                      RANGE
                                        (kN)

 7           6.46607466162E-05 -1440              -1296
 8           2.58642986465E-04 -1296              -1152
 9           3.31925165963E-03 -1152              -1008
 10          .017523062333     -1008              -864
 11          7.11268212778E-02 -864               -720
 12          .341904474524     -720               -576
 13          2.55920769032     -576               -432
 14          4.28871023365     -432               -288
 19          .309617208381      288                432
 20          .118674023623      432                576
 21          .017630830244      576                720
 22          2.80196568670E-04  720                864
```

DATA IS FOR A TOTAL OF 32.2 DAYS
DURING A DATA COLLECTION
PERIOD OF 117 DAYS

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: THRUST PEAKS PER MINUTE, RECORDED AT A HYSTERESIS OF TWO, FOR THE PERIOD 84-07-04 TO 84-10-29**
		TABLE No. 20

SUM OF ALL THRUST #5 DATAMYTES RUN START: 84/07/04



**DATA IS FOR A TOTAL OF 32.2 DAYS
DURING A DATA COLLECTION
PERIOD OF 117 DAYS**

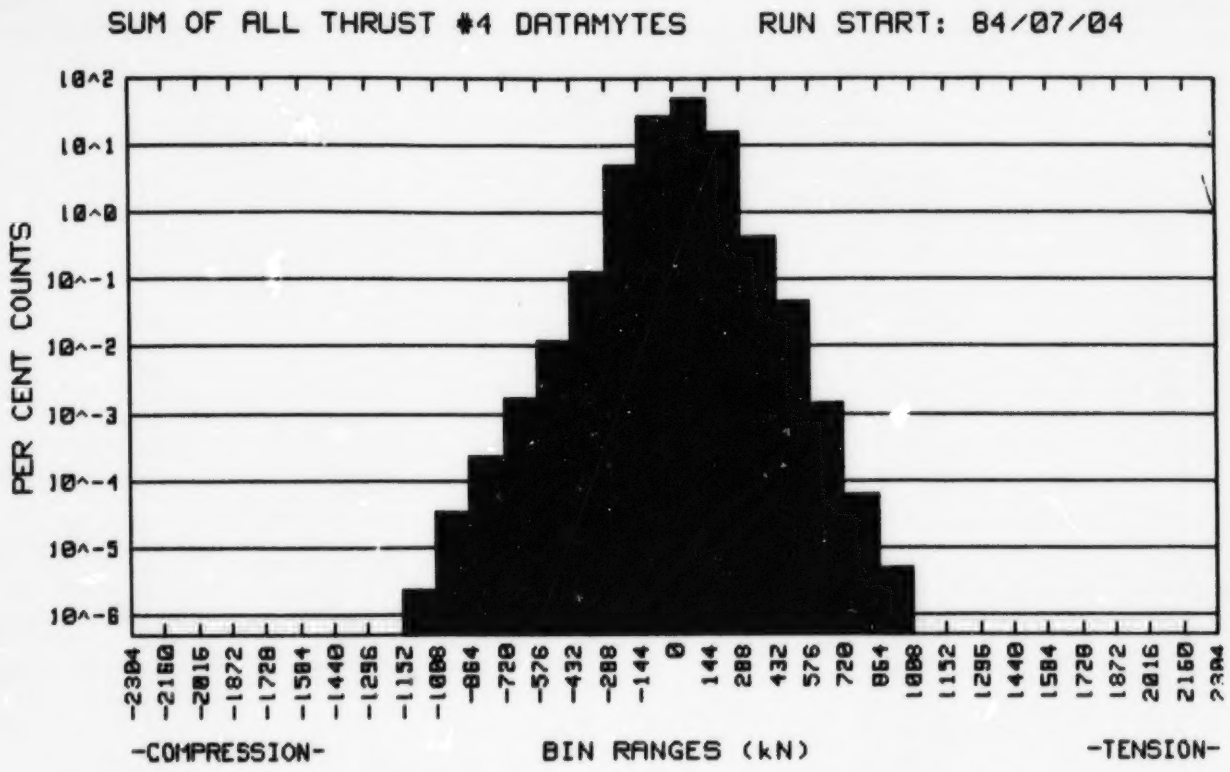
CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: THRUST PEAKS PER MINUTE, RECORDED AT A HYSTERESIS OF TWO HISTORGRAMS, FOR THE PERIOD 84-07-04 TO 84-10-29**
		FIGURE No. 8

DATAMYTE 400 HISTOGRAM FOR SUM OF ALL THRUST #4 DATAMYTES
DATA COLLECTION BEGUN AT 22:20:00 ON 84/07/04
ELAPSED TIME DURING DATA COLLECTION: 114.677 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
CALIBRATION: 144 kN / BIN

INDEX NUMB.	COUNTS AT 2400/SEC.	PER CENT OF COUNTS	LEVEL CROSSINGS	PER CENT OF LEVEL CROSSINGS	RANGE (kN)	
1	0	0.000000	0	0.000000	-2304	-2160
2	0	0.000000	0	0.000000	-2160	-2016
3	0	0.000000	0	0.000000	-2016	-1872
4	0	0.000000	0	0.000000	-1872	-1728
5	0	0.000000	0	0.000000	-1728	-1584
6	0	0.000000	0	0.000000	-1584	-1440
7	6	.000000	4	.000001	-1440	-1296
8	42	.000000	27	.000004	-1296	-1152
9	540	.000002	337	.000044	-1152	-1008
10	7732	.000032	3576	.000464	-1008	-864
11	52301	.000220	22176	.002879	-864	-720
12	381214	.001600	134677	.017485	-720	-576
13	2903335	.012189	912563	.118476	-576	-432
14	31635745	.132817	9948539	1.291597	-432	-288
15	1231513641	5.170287	176558928	22.922263	-288	-144
16	6374260850	26.761178	62574933	8.123968	-144	0
17	12146273877	50.993928	236659992	30.725054	0	144
18	3914728336	16.435277	259246385	33.657397	144	288
19	105605733	.443367	20730486	2.691394	288	432
20	11352489	.047661	3331048	.432463	432	576
21	327278	.001374	121723	.015803	576	720
22	14563	.000061	5067	.000658	720	864
23	1209	.000005	357	.000046	864	1008
24	67	.000000	32	.000004	1008	1152
25	0	0.000000	0	0.000000	1152	1296
26	0	0.000000	0	0.000000	1296	1440
27	0	0.000000	0	0.000000	1440	1584
28	0	0.000000	0	0.000000	1584	1728
29	0	0.000000	0	0.000000	1728	1872
30	0	0.000000	0	0.000000	1872	2016
31	0	0.000000	0	0.000000	2016	2160
32	0	0.000000	0	0.000000	2160	2304

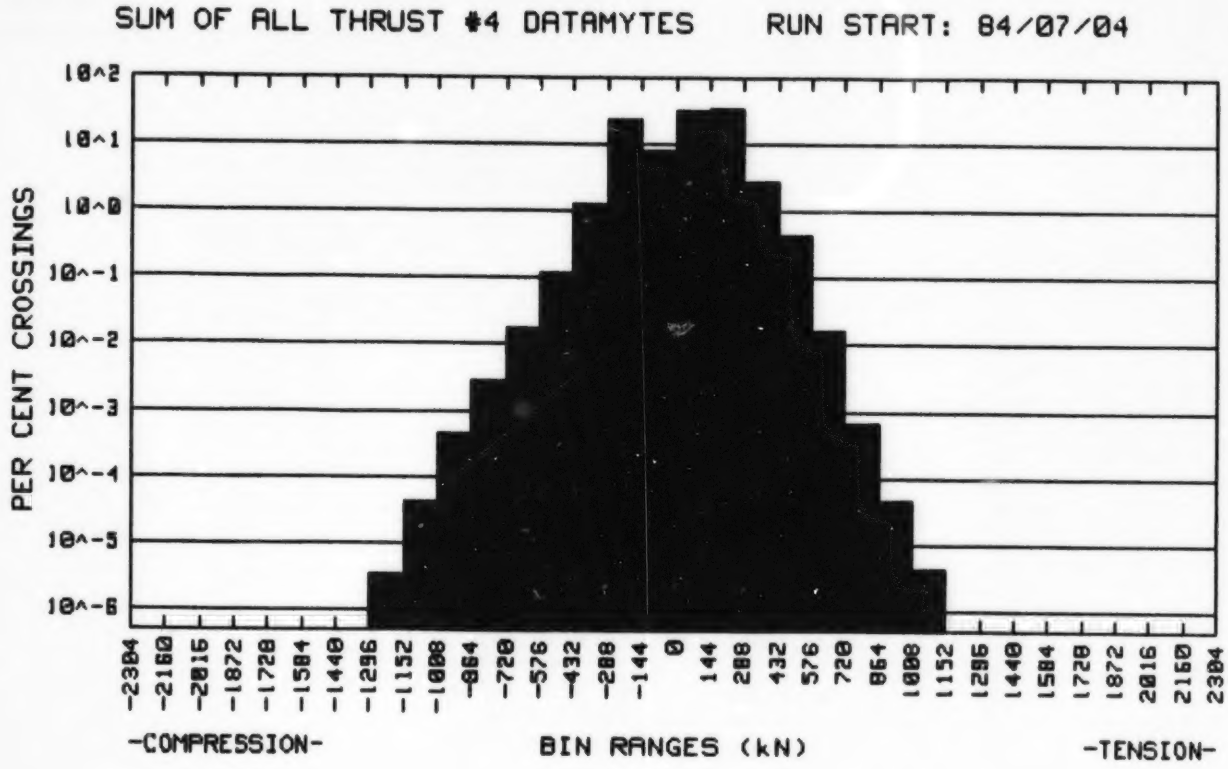
**DATA IS FOR A TOTAL OF 114.7 DAYS
DURING A DATA COLLECTION
PERIOD OF 117 DAYS HYSTERESIS = 2**

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: THRUST TIME LEVEL PLUS LEVEL CROSSING COUNTS, FOR THE PERIOD 84-07-04 TO 84-10-29**
		TABLE No. 21



**DATA IS FOR A TOTAL OF 114.7 DAYS
DURING A DATA COLLECTION
PERIOD OF 117 DAYS**

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: THRUST PERCENT TIME AT LEVEL HISTOGRAM, FOR THE PERIOD 84-07-04 TO 84-10-29**
		FIGURE No. 9



DATA IS FOR A TOTAL OF 114.7 DAYS
DURING A DATA COLLECTION
PERIOD OF 117 DAYS

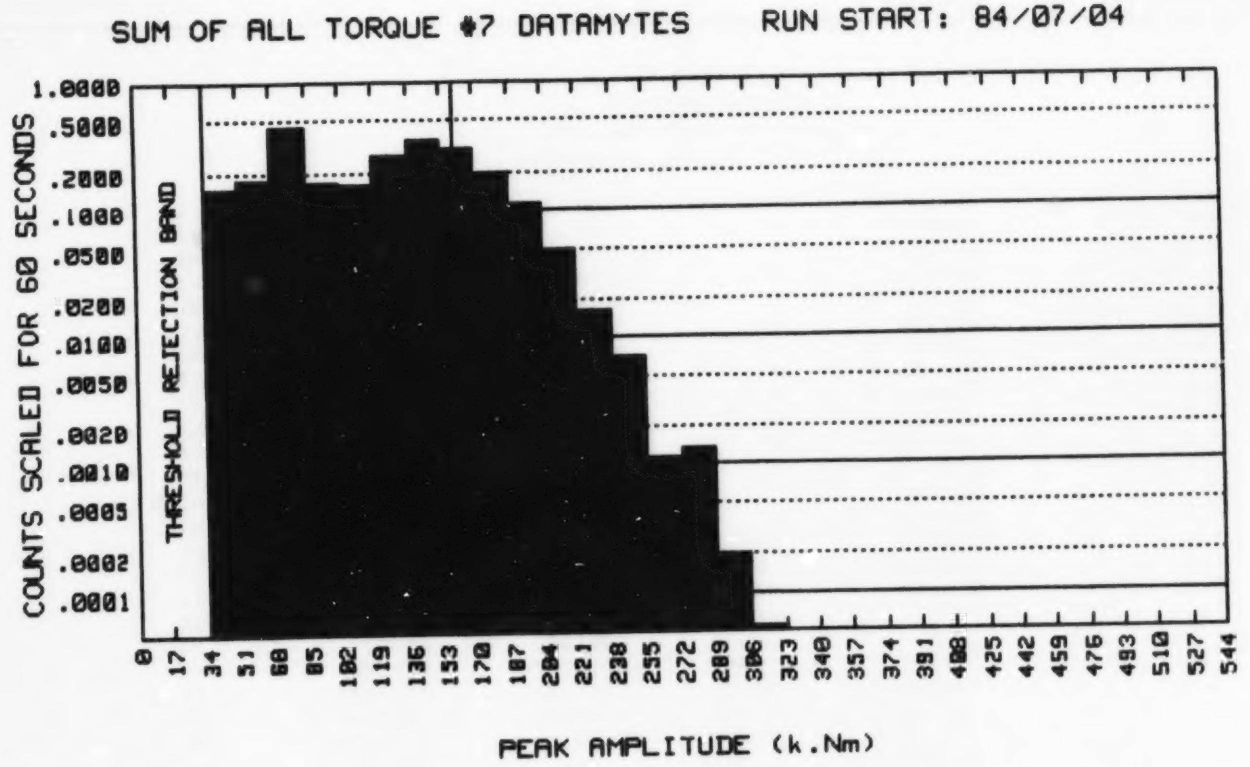
HYSTERESIS = 2

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: THRUST PERCENT LEVEL CROSSING HISTOGRAM, FOR THE PERIOD 84-07-04 TO 84-10-29**
		FIGURE No. 10

```
                MV R LEMEUR PROPELLER BLADE TESTS
                    DATAMYTE 400 SCALED DATA

AMPLITUDE-FREQUENCY HISTOGRAM FOR SUM OF ALL TORQUE #7 DATAMYTES
BASED UPON DATA COLLECTION BEGUN AT 22:22:00 ON 84/07/04
ELAPSED TIME DURING DATA COLLECTION: 114.822916667 DAYS
DATA SCALED FOR 60 SECONDS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
CALIBRATION: 17 k.Nm / BIN
PHYSICAL DAMAGE LIMIT:  1347 k.Nm

HYSTERESIS: 2                  BIAS:  0

BIN        COUNT                       RANGE
                                      (k.Nm)
 3          .151186912214       34               51
 4          .177338292661       51               68
 5          .450893586138       68               85
 6          .16858084611        85               102
 7          .162466358221       102              119
 8          .265511506245       119              136
 9          .362938099126       136              153
 10         .305881641416       153              170
 11         .200441501104       170              187
 12         .112933563156       187              204
 13         4.96356103904E-02   204              221
 14         1.64141643231E-02   221              238
 15         7.14264114427E-03   238              255
 16         1.12492062052E-03   255              272
 17         1.35474311289E-03   272              289
 18         1.99582690738E-04   289              306
 19         5.44316429284E-05   306              323
 20         6.04796032538E-06   323              340
```

DATA IS FOR A TOTAL OF 114.8 DAYS
DURING A DATA COLLECTION
PERIOD OF 117 DAYS

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: TORQUE PEAKS PER MINUTE, FOR THE PERIOD 84-07-04 TO 84-10-29**
		TABLE No. 22



DATA IS FOR A TOTAL OF 114.7 DAYS
DURING A DATA COLLECTION
PERIOD OF 117 DAYS

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: TORQUE PEAKS PER MINUTE HISTOGRAM, FOR THE PERIOD 84-07-04 TO 84-10-29**
		FIGURE No. 11

DATAMYTE 400 HISTOGRAM FOR SUM OF ALL TORQUE #6 DATAMYTES
DATA COLLECTION BEGUN AT 22:21:00 ON 84/07/04
ELAPSED TIME DURING DATA COLLECTION: 114.665 DAYS
ICE CONDITION DURING DATA COLLECTION: ASSORTED
CALIBRATION: 17 kN.m / BIN

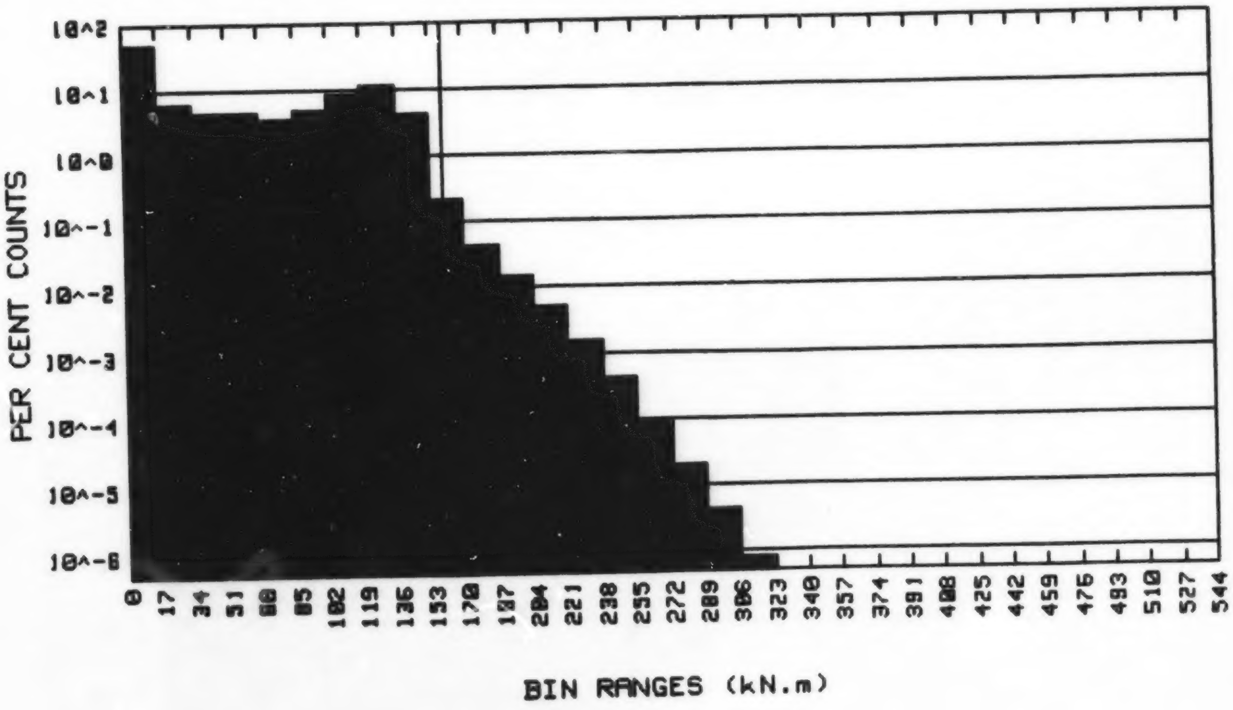
INDEX NUMB.	COUNTS AT 800/SEC.	PER CENT OF COUNTS	LEVEL CROSSINGS	PER CENT OF LEVEL CROSSINGS	RANGE (kN.m)	
1	3989060680	50.247254	49100	2.744769	0	17
2	516243109	6.502733	112548	6.291615	17	34
3	374254837	4.714212	136642	7.638509	34	51
4	370512576	4.667074	140693	7.864966	51	68
5	294441873	3.708867	127168	7.108897	68	85
6	399527665	5.032555	151444	8.465965	85	102
7	694969501	8.754018	219649	12.278734	102	119
8	928937103	11.701135	262257	14.660591	119	136
9	348328305	4.387635	239272	13.375692	136	153
10	17393873	.219098	169991	9.502772	153	170
11	3415302	.043020	99550	5.565006	170	187
12	1188822	.014975	49382	2.760534	187	204
13	422173	.005318	20510	1.146542	204	221
14	125703	.001583	7401	.413728	221	238
15	32503	.000410	2368	.132375	238	255
16	7026	.000089	666	.037230	255	272
17	1571	.000020	167	.009336	272	289
18	331	.000004	41	.002292	289	306
19	64	.000001	7	.000391	306	323
20	2	.000000	1	.000056	323	340
21	0	0.000000	0	0.000000	340	357
22	0	0.000000	0	0.000000	357	374
23	0	0.000000	0	0.000000	374	391
24	0	0.000000	0	0.000000	391	408
25	0	0.000000	0	0.000000	408	425
26	0	0.000060	0	0.000000	425	442
27	0	0.000000	0	0.000000	442	459
28	0	0.000000	0	0.000000	459	476
29	0	0.000000	0	0.000000	476	493
30	0	0.000000	0	0.000000	493	510
31	0	0.000000	0	0.000000	510	527
32	0	0.000000	0	0.000000	527	544

DATA IS FOR A TOTAL OF 114.7 DAYS
DURING A DATA COLLECTION
PERIOD OF 117 DAYS

HYSTERESIS = 2

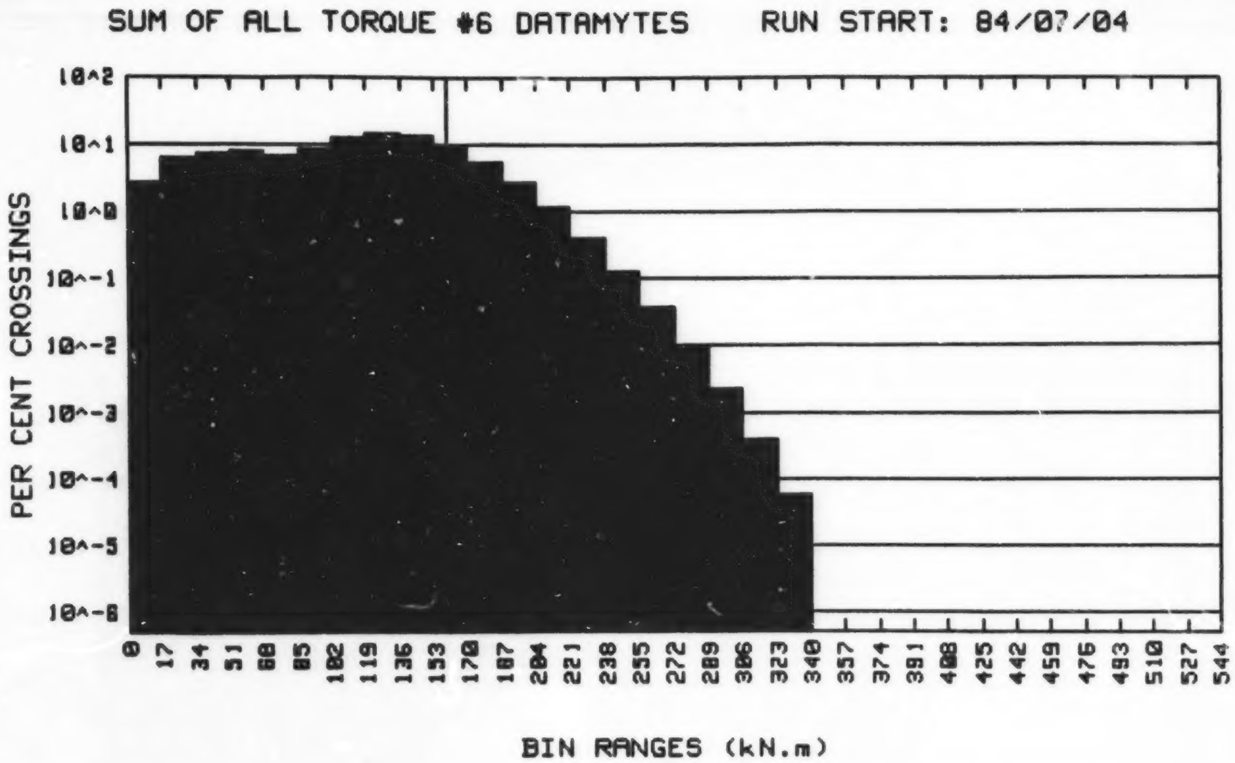
CANMAR **CANADIAN MARINE DRILLING LIMITED**	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: TORQUE TIME AT LEVEL PLUS LEVEL CROSSING, FOR THE PERIOD 84-07-04 TO 84-10-29** **TABLE No. 23**

SUM OF ALL TORQUE #6 DATAMYTES RUN START: 84/07/04



DATA IS FOR A TOTAL OF 114.7 DAYS
DURING A DATA COLLECTION
PERIOD OF 117 DAYS

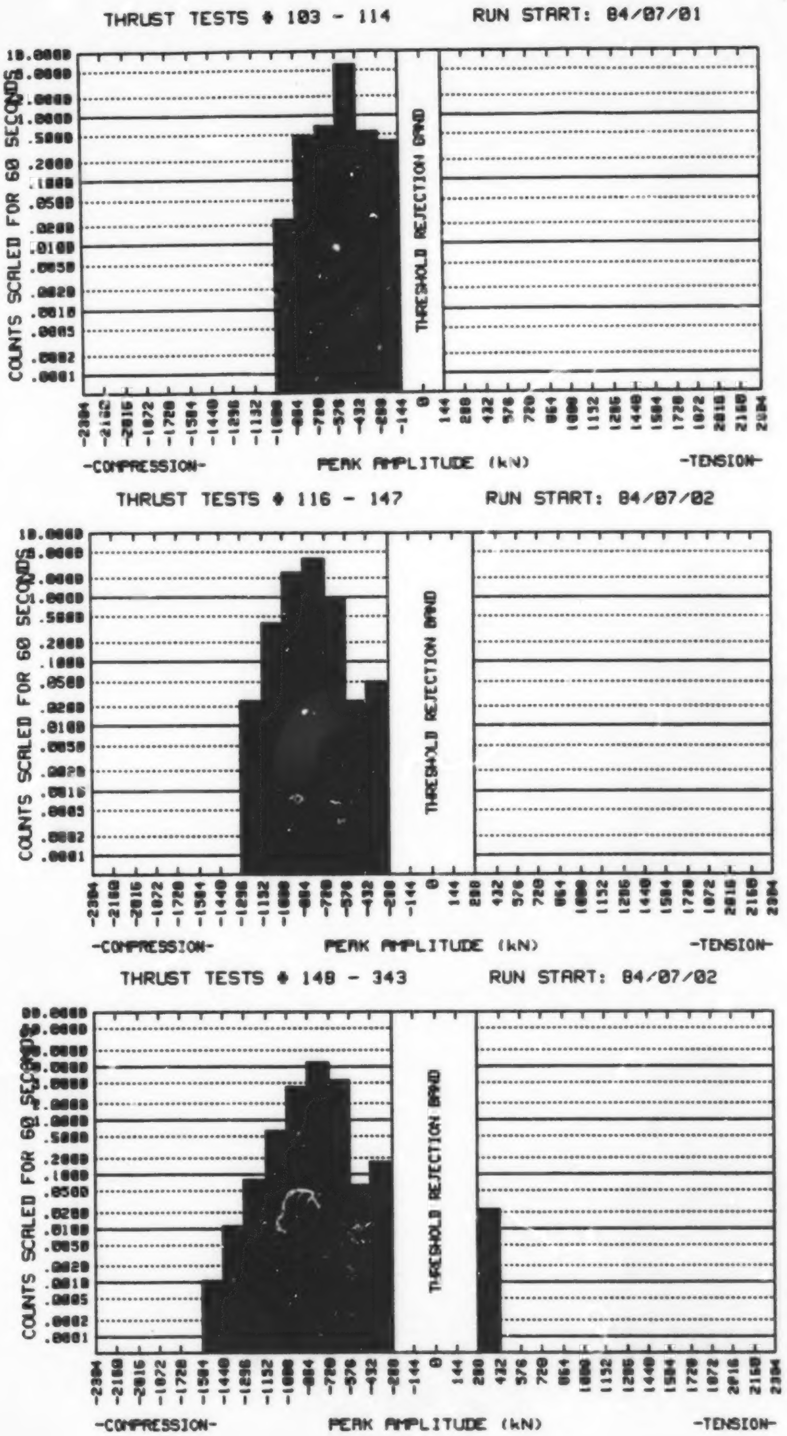
CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: TORQUE PERCENT TIME AT LEVEL HISTOGRAM, FOR THE PERIOD 84-07-04 TO 84-10-29**
		FIGURE No. 12



DATA IS FOR A TOTAL OF 114.7 DAYS
DURING A DATA COLLECTION
PERIOD OF 117 DAYS

HYSTERESIS = 2

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: TORQUE PERCENT LEVEL CROSSINGS HISTOGRAM, FOR THE PERIOD 84-07-04 TO 84-10-29
		FIGURE No. 13



A
HYS = 1

B
HYS = 2

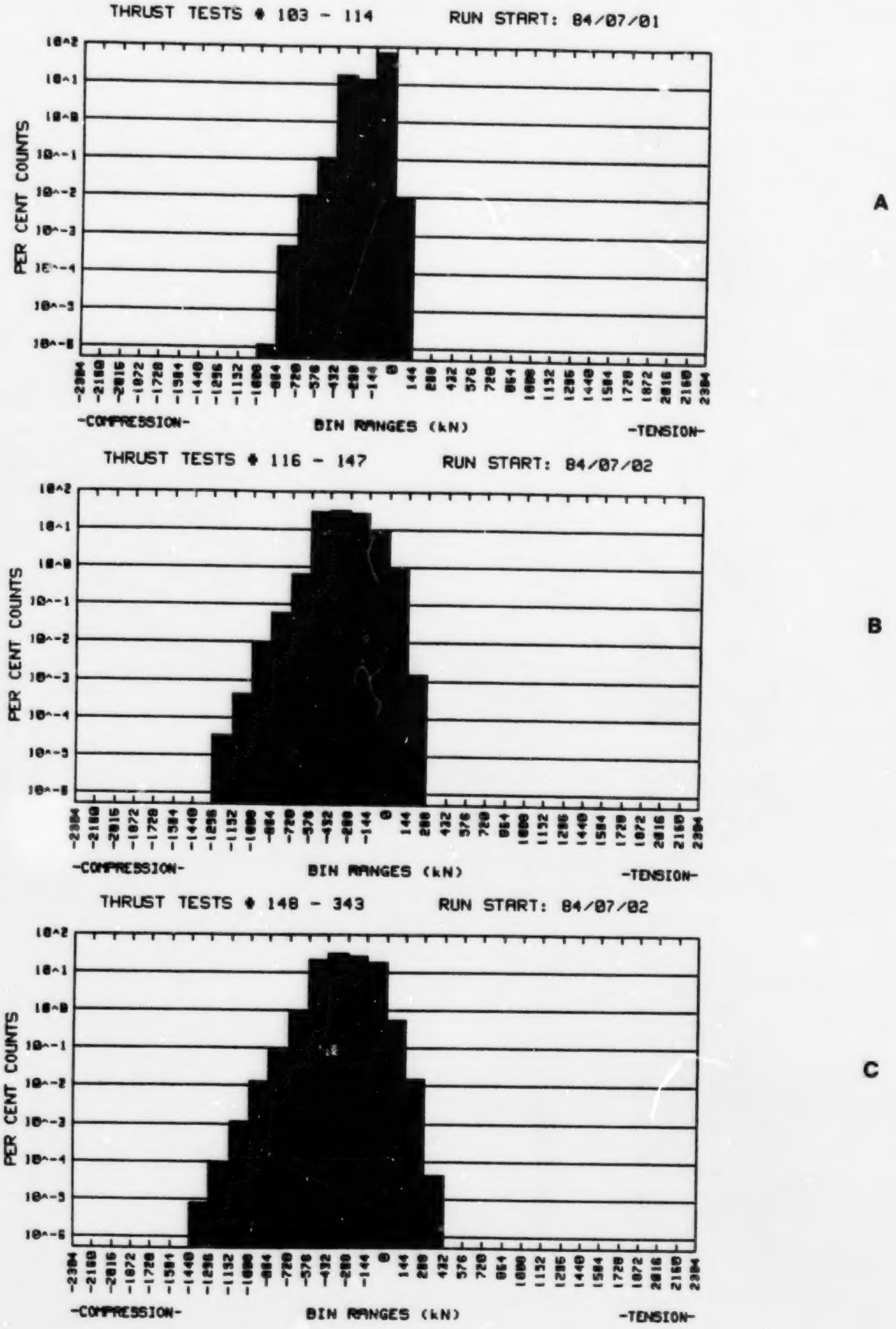
C
HYS = 2

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
THRUST PEAKS PER MINUTE, FOR THE 343 DETAILED TESTS

FIGURE No. 14

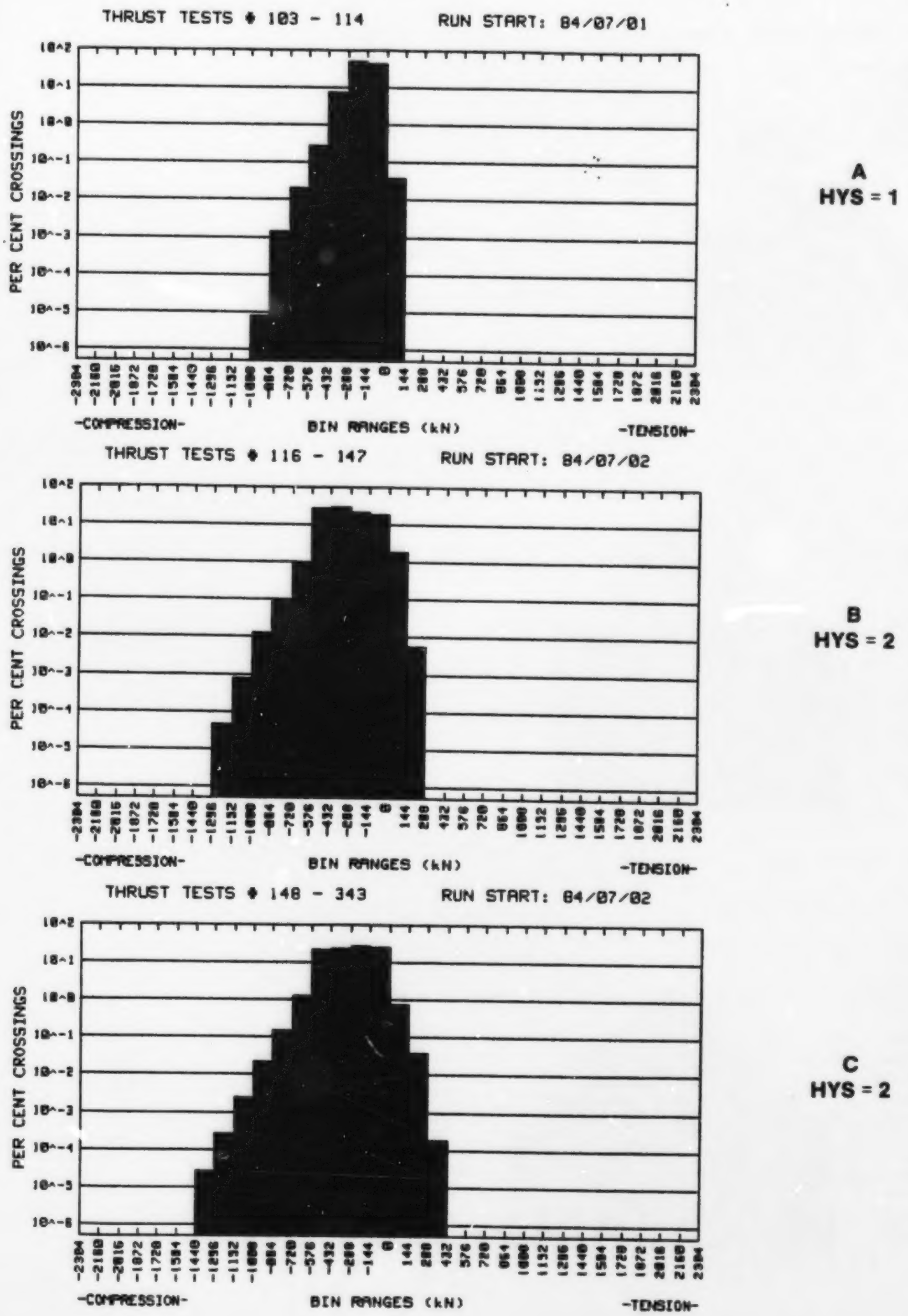


CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
THRUST PERCENT TIME AT LEVEL, FOR THE 343 DETAILED TESTS

FIGURE No. 15

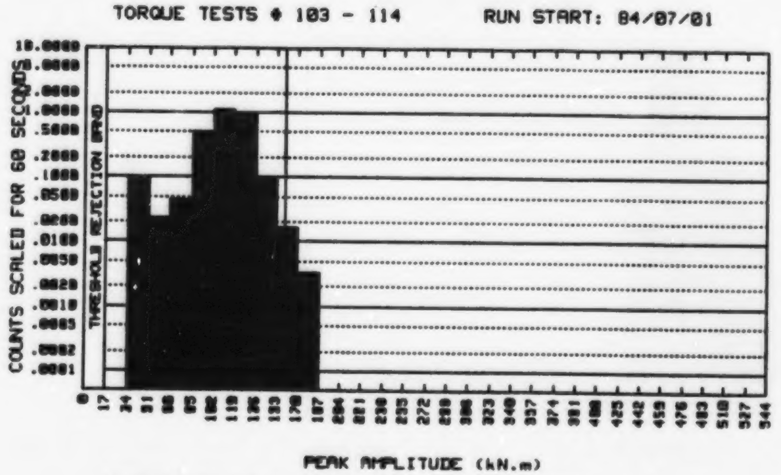


CANADIAN MARINE DRILLING LIMITED

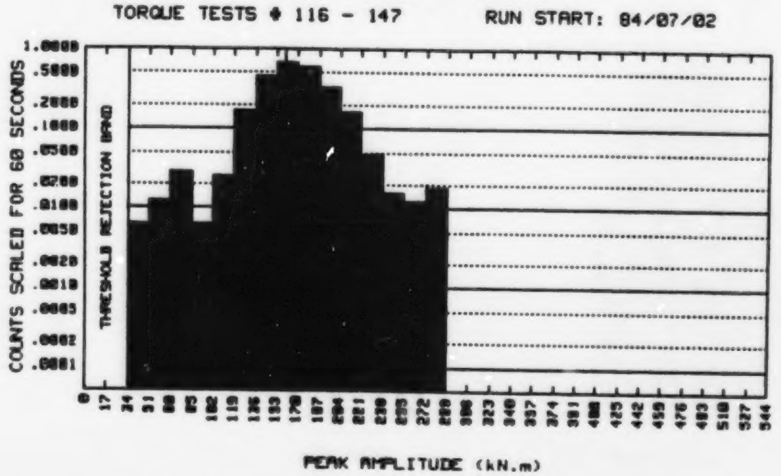
MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: THRUST PERCENT LEVEL CROSSINGS, FOR THE 343 DETAILED TESTS

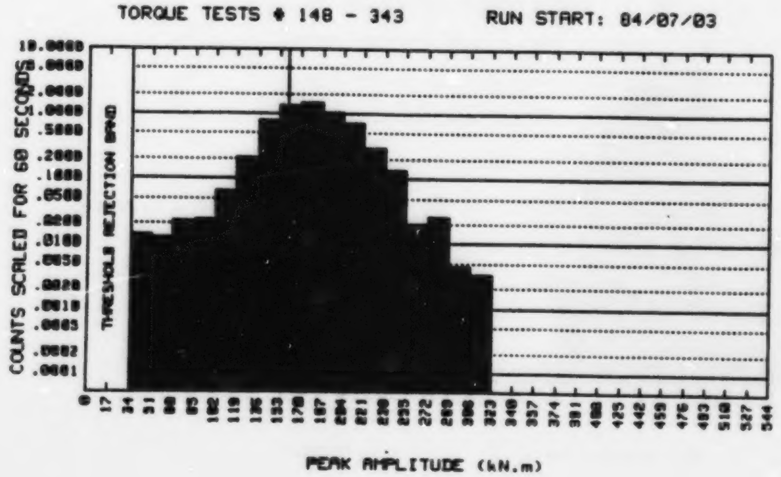
FIGURE No. 16



A
HYS = 1



B
HYS = 2



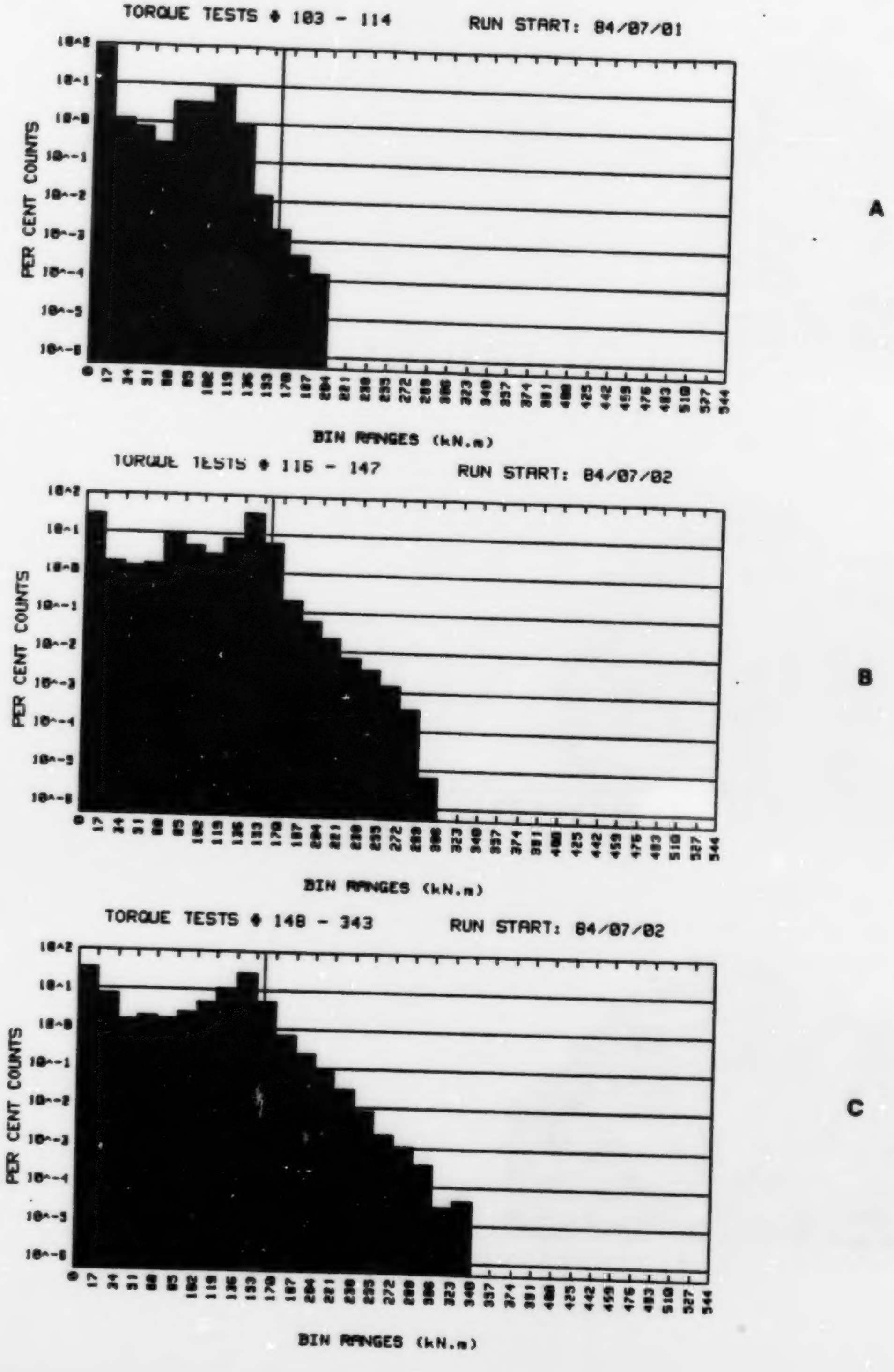
C
HYS = 2

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
TORQUE PEAKS PER MINUTE, FOR THE 343 DETAILED TESTS

FIGURE No. 17


TORQUE TESTS # 103 - 114 RUN START: 84/07/01

TORQUE TESTS # 116 - 147 RUN START: 84/07/02

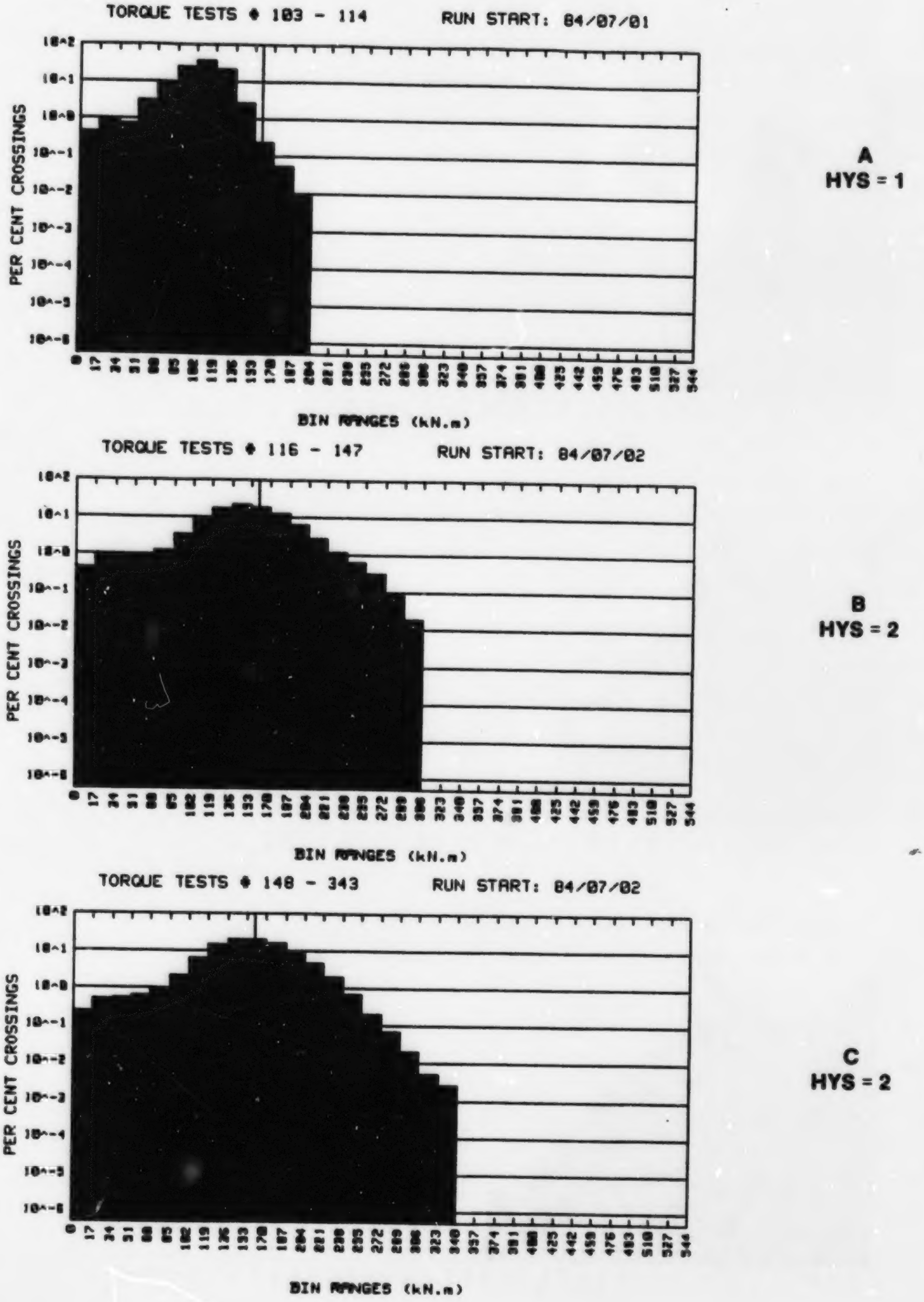
TORQUE TESTS # 148 - 343 RUN START: 84/07/02

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
TORQUE PERCENT TIME AT LEVEL, FOR THE 343 DETAILED TESTS

FIGURE No. 18



CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE: TORQUE PERCENT LEVEL CROSSINGS, FOR THE 343 DETAILED TESTS**
		FIGURE No. 19

APPENDIX F

EVENTS FROM THE MOTION RECORDER

(DCS-302 DATA)

SOURCE: CANMAR

LIST OF TABLES

TABLE 1 Log of MV Robert LeMeur Sample Torque, Thrust and Ship's Speed Recordings, Tape No. 1, Installed 84-08-07, Removed 84-08-08 1

TABLE 2 Log of MV Robert LeMeur Sample Torque, Thrust and Ship's Speed Recordings, Tape No. 2, Installed 84-08-08, Removed 84-09-20 3

TABLE 3 Log of MV Robert LeMeur Sample Torque, Thrust and Ship's Speed Recordings, Tape No. 3, Installed 84-09-20, Removed 84-10-02 5

TABLE 4 Log of MV Robert LeMeur Sample Torque, Thrust and Ship's Speed Recordings, Tape No. 4, Installed 84-10-02, Removed 84-10-26 7

TABLE 5 Log of MV Robert LeMeur Sample Torque, Thrust and Ship's Speed Recordings, Tape No. 5, Installed 84-10-16, Removed 84-10-29 8

LOG OF M.V. ROBERT LEMEUR SAMPLE TORQUE, THRUST AND SHIP'S SPEED RECORDINGS, TAPE NO. 1, INSTALLED 84-08-07, REMOVED 84-08-08

				TORQUE		
EVENT #	JULIAN DAY	DATE	TIME	MEAN VOLTS	PEAK VOLTS	COMMENTS
00	220	84-08-07	23:22:30	0.925	1.55	Tape used to set-up recorder Trigger at 0.250 V Torque = 136 kN.m/V Thrust = 1150 kN/V
01	220	84-08-07	23:23:00	0.975	1.475	
02	220	84-08-07	23:23:40	0.912	1.475	
03	220	84-08-07	23:24:10	1.00	1.350	
04	220	84-08-07	23:25:20	0.815	1.400	
05	220	84-08-07	23:27:20	0.825	1.288	
06	220	84-08-07	23:28:40	0.812	1.425	Long Event.
07	220	84-08-07	23:30:30	0.800	1.350	
08	220	84-08-07	23:31:50	0.880	1.375	
09	220	84-08-07	23:32:50	0.900	1.375	
10	220	84-08-07	23:34:10	0.800	1.550	Steady Torque Rise.
11	220	84-08-07	23:34:30	0.950	1.425	Increased Trigger Level to 0.330 V
12	220	84-08-07	23:36:10	0.800	1.500	Torque High for 0.75 sec.
13	220	84-08-07	23:39:40	0.750	1.200	
14	220	84-08-07	23:41:30	1.000	1.550	Long Events 3 sec.
15	220	84-08-07	23:45:10	1.000	1.615	
16	220	84-08-07	23:47:30	0.900	1.800	Sharp Individual Peaks.
17	220	84-08-07	23:51:40	0.925	1.925	Steady Rise In Torque Good Event
18	220	84-08-07	23:53:30	0.750	1.400	
19	220	84-08-07	23:53:50	0.950	1.675	Milling
20	221	84-08-08	00:00:10	0.875	1.425	
21	221	84-08-08	00:01:20	0.925	1.410	

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:
EVENTS FROM THE MOTION RECORDER (DCS-302 DATA)

APPENDIX F

LOG OF M.V. ROBERT LEMEUR SAMPLE TORQUE, THRUST AND SHIP'S SPEED RECORDINGS, TAPE NO. 1, INSTALLED 84-08-07, REMOVED 84-08-08 (CONT'D)

				TORQUE		
EVENT #	JULIAN DAY	DATE	TIME	MEAN VOLTS	PEAK VOLTS	COMMENTS
22	221	84-08-08	00:03:10	0.825	1.475	Multiple Interactions.
23	221	84-08-08	00:03:50	0.950	1.975	Nice Event.
24	221	84-08-08	00:05:40	0.800	1.325	
25	221	84-08-08	00:08:40	0.700	1.625	Nice Event, Large.
26	221	84-08-08	00:09:40	1.075	1.400	
27	221	84-08-08	00:12:30	0.875	1.550	
28	221	84-08-08	00:16:20	0.950	1.425	
29	221	84-08-08		0.900	1.512	
30	221	84-08-08		0.800	1.262	
31	221	84-08-08	00:21:30	0.850	1.405	Short, Isolated 0.5 sec.
32	221	84-08-08	00:27:40	0.775	1.325	
33	221	84-08-08	00:30:20	0.775	1.150	
34	221	84-08-08	00:38:20	0.875	1.250	
35	221	84-08-08	00:43:30	0.875	1.425	
36	221	84-08-08	00:52:20	0.750	1.525	Long Event 3 sec After this event set trigger level to 0.510 V.
37	221	84-08-08	10:37:00			Recorded was disconnected.
38	221	84-08-08	11:10:00	1.000	1.775	Nice Event, rise in mean level of torque
		84-08-08	12:16			Raised trigger to 0.750 V.
		84-08-08	19:15			No more events, raised trigger to 1.000 V and installed new tape.

LOG OF M.V. ROBERT LEMEUR SAMPLE TORQUE, THRUST AND SHIP'S SPEED RECORDINGS, TAPE NO. 2, INSTALLED 84-08-08, REMOVED 84-09-20

EVENT #	JULIAN DAY	DATE	TIME	TORQUE MEAN VOLTS	TORQUE PEAK VOLTS	COMMENTS
00	248	84-09-04	16:31:20			Manual Scan after lowering trigger level to 0.500 V.
01	252	84-09-08	15:42:30	0.815	1.688	Nice Sharp Event.
02	252	84-09-08	20:10:00	0.950	1.625	Lasts 0.5 sec.
03	252	84-09-08	20:26:10	0.950	1.838	
04	252	84-09-08	22:48:10	0.850	1.362	
05	253	84-09-09	11:10:50			Power outage.
06	253	84-09-09	11:14:40			Power came back on.
07	253	84-09-09	11:19:00			Momentary power outage.
08	253	84-09-09	11:34:10	0.850	1.075	
09	253	84-09-09	11:37:00			No apparent event.
10	253	84-09-09	11:39:40			No apparent event. Slow change in torque and thrust.
11	253	84-09-09	11:46:00			No apparent event. Slow change in torque and thrust.
12	253	84-09-09	11:49:40			No apparent event.
13	253	84-09-09	11:50:20			No apparent event.
14	253	84-09-09	11:51:40			No apparent event.
15	253	84-09-09	12:14:10			No apparent event.
16	253	84-09-09	12:14:30	0.900	1.412	This event did not cause the trigger.
17	253	84-09-09	12:17:10			No apparent event.
18	253	84-09-09	12:17:50			No apparent event.
19	253	84-09-09	12:19:30	1.025	1.825	Nice event.
20	253	84-09-09	12:20:20			No apparent event.

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **EVENTS FROM THE MOTION RECORDER (DCS-302 DATA)** **APPENDIX F**

LOG OF M.V. ROBERT LEMEUR SAMPLE TORQUE, THRUST AND SHIP'S SPEED RECORDINGS, TAPE NO. 2, INSTALLED 84-08-08, REMOVED 84-09-20 (CONT'D)

				TORQUE		
EVENT #	JULIAN DAY	DATE	TIME	MEAN VOLTS	PEAK VOLTS	COMMENTS
21	253	84-09-09	12:20:50	1.000	1.475	
22	253	84-09-09	12:24:30			No apparent event.
23	253	84-09-09	12:24:40			No apparent event.
24	253	84-09-09	12:31:30	0.925	1.362	
25	253	84-09-09	12:32:20			No apparent event.
26	253	84-09-09	12:32:50			No apparent event.
27	253	84-09-09	12:33:50			No apparent event.
28	253	84-09-09		1.025	1.650	Nice short event.
29	253	84-09-09	12:39:50			No apparent event.
30	253	84-09-09	12:42:20			No apparent event.
31	253	84-09-09	12:43:40			No apparent event.
32	253	84-09-09	12:44:00			No apparent event.
33	253	84-09-09	12:45:40	1.000	1.362	Probably did not trigger because of this event.
34	253	84-09-09	12:46:00	0.925	1.600	Nice events.
35	253	84-09-09	12:46:30	0.025	0.725	Continuation of previous event.
36	253	84-09-09	12:47:10			No apparent event. End of Tape

LOG OF M.V. ROBERT LEMEUR SAMPLE TORQUE, THRUST AND SHIP'S SPEED RECORDINGS, TAPE NO. 3, INSTALLED 84-09-20, REMOVED 84-10-02

EVENT #	JULIAN DAY	DATE	TIME	TORQUE MEAN VOLTS	TORQUE PEAK VOLTS	COMMENTS
						PREVIOUS TAPE HAD RUN OUT
73		84-09-20				Used to start tape.
74	264	84-09-20	20:06:00			Shaft stopped, no event.
75	264	84-09-20	20:06:10			Power turned on.
76	276	84-10-02	16:10:00			Shaft stopped.
77	276	84-10-02	17:19:40			Caused by system voltage checks, no good readings.
78	276	84-10-02	17:31:00	0	1.525	Shunt cal of torque, 501.5 k across arm and dropping res.
79	276	84-10-02	17:31:40	1.525	0	Unplugged torque amp sig.
80	276	84-10-02	17:32:00	-0.05	1.500	Plugged torque amp sig. back in.
81	276	84-10-02	17:32:30	1.525	0	Changed shunt cal res. to opposite arm and dropping res.
82	276	84-10-02	17:33:20	1.525	-0.05	Unplugged torque amp sig.
83	276	84-10-02	17:33:40	-0.05	1.500	Plugged torque amp sig. back in.
84	276	84-10-02	17:34:10	1.525	0	Moved shunt cal res. 501.5 k to just one arm of bridge.
85	276	84-10-02	17:35:20	1.025	-0.05	Unplugged torque amp sig.
86	276	84-10-02	17:35:40	-0.05	1.025	Plugged torque amp sig. back in.
87	276	84-10-02	17:36:40	1.025	-0.05	Removed shunt cal res.
88	276	84-10-02	17:36:50	-0.05	1.025	Installed shunt cal res. 501.5 k on opposite arm of bridge and unplugged amp sig.

LOG OF M.V. ROBERT LEMEUR SAMPLE TORQUE, THRUST AND SHIP'S SPEED RECORDINGS, TAPE NO. 3, INSTALLED 84-09-20, REMOVED 84-10-02 (CONT'D)

EVENT #	JULIAN DAY	DATE	TIME	TORQUE MEAN VOLTS	TORQUE PEAK VOLTS	COMMENTS
89	276	84-10-02	17:37:30	-0.05	1.025	Plugged amp sig. back in.
90	276	84-10-02	17:43:20	1.025	-0.05	Removed shunt 501.5 k shunt and placed 349.5 k shunt on one arm bridge.
91	276	84-10-02	17:46:40	1.450	-0.05	Unplugged sig. from amp.
92	276	84-10-02	17:47:00	-0.05	1.450	Plugged amp sig. back in.
93	276	84-10-02	17:57:10	1.450	-0.05	Moved shunt cal. 349.5 k to opposite arm of bridge.
94	276	84-10-02	17:58:10	1.450	-0.05	Unplugged and plugged back in the amp sig.
95	276	84-10-02	18:07:10	1.450	0	Removed shunt cal.
96	276	84-10-02	18:10:40			Manual scan.
97	276	84-10-02	20:29:10			Momentarily lowered trigger to check for proper operation. Reset trigger level to 0.507 V. Reset event counter to 00.

LOG OF M.V. ROBERT LEMEUR SAMPLE TORQUE, THRUST AND SHIP'S SPEED RECORDINGS, TAPE NO. 4, INSTALLED 84-10-02, REMOVED 84-10-26

EVENT #	JULIAN DAY	DATE	TIME	TORQUE MEAN VOLTS	TORQUE PEAK VOLTS	COMMENTS
00	278	84-10-04	00:19:00	1.00	1.64	Large event.
01	280	84-10-06	17:48:30	0.88	1.58	Sharp event.
02	284	84-10-10	03:35:40	0.15	0.15	No apparent cause.
						TAPE CHANGED BEFORE NEXT RECORDED EVENT.

LOG OF M.V. ROBERT LEMEUR SAMPLE TORQUE, THRUST AND SHIP'S SPEED RECORDINGS, TAPE NO. 5, INSTALLED 84-10-16, REMOVED 84-10-29

EVENT #	JULIAN DAY	DATE	TIME	TORQUE MEAN VOLTS	PEAK VOLTS	COMMENTS
03	290	84-10-16	13:09:30	0	0	Manual trigger when tape installed.
04	292	84-10-18	05:25:10	0.40	0.40	Power went off.
05	292	84-10-18	05:25:50	0.50	0.50	Power came back on.
06	292	84-10-18	05:26:50			No apparent cause, no events.
07	292	84-10-18	07:13:20			No apparent cause, no events.
08	292	84-10-18	07:50:50			No apparent cause, no events.
09	292	84-10-18	07:55:20			No apparent cause, no events.
10	292	84-10-18	07:56:40			No apparent cause, no events.
11	292	84-10-18	07:57:00			No apparent cause, no events.
12	292	84-10-18	07:59:50			No apparent cause, no events.
13	292	84-10-18	10:25:20			No apparent cause, no events.
14	292	84-10-18	10:28:20			No apparent cause, no events.
15	292	84-10-18	10:36:40			No apparent cause, no events.
16	292	84-10-18	10:47:40			No apparent cause, no events.
17	292	84-10-18	10:48:30			No apparent cause, no events.
18	292	84-10-18	10:49:30			No apparent cause, no events.
19	292	84-10-18	11:01:50			No apparent cause, no events.
20	292	84-10-18	11:02:20			No apparent cause, no events.
21	292	84-10-18	11:11:20			No apparent cause, no events.
22	292	84-10-18	11:13:30			No apparent cause, no events.
23	292	84-10-18	11:15:20			No apparent cause, no events.
24	292	84-10-18	11:19:40			No apparent cause, no events.
25	292	84-10-18	11:21:40			No apparent cause, no events.
26	292	84-10-18	11:22:20			No apparent cause, no events.
27	292	84-10-18	11:24:10			No apparent cause, no events.

LOG OF M.V. ROBERT LEMEUR SAMPLE TORQUE, THRUST AND SHIP'S SPEED RECORDINGS, TAPE NO. 5, INSTALLED 84-10-16, REMOVED 84-10-29 (CONT'D)

				TORQUE		
EVENT #	JULIAN DAY	DATE	TIME	MEAN VOLTS	PEAK VOLTS	COMMENTS
28	292	84-10-18	11:33:00			No apparent cause, no events.
29	292	84-10-18	11:33:30			No apparent cause, no events.
30	292	84-10-18	11:43:40			No apparent cause, no events.
31	292	84-10-18	12:19:00			No apparent cause, no events.
32	292	84-10-18	12:19:30			No apparent cause, no events.
33	292	84-10-18	12:52:00			No apparent cause, no events.
34	292	84-10-18	13:17:00			No apparent cause, no events.
35	292	84-10-18	13:31:50			No apparent cause, no events.
36	292	84-10-18	13:56:10			No apparent cause, no events.
37	292	84-10-18	14:00:00			No apparent cause, no events.
38	292	84-10-18	14:05:20			No apparent cause, no events.
39	292	84-10-18	14:21:50			No apparent cause, no events.
40	292	84-10-18	14:46:00			No apparent cause, no events.

DISPLAY READ EVENT #23. WHEN THIS TAPE WAS REMOVED.

APPENDIX G

PROPULSION TRAIN TORSIONAL AND LONGITUDINAL MODEL DEVELOPMENT

SOURCE: CANMAR

TORSIONAL MODEL (See Figure 4.9.2-1)

List of Parameters:

Location	J $kg*m^2$	K_T kN*m/rad.
1	413	581
2	146	413
3	274	18,950

NOTES:

A) J1 includes water addition.

B) J1 = 304 $kg*m^2$ in air.

Equations of Motion:

$$[J][\ddot{\theta}] + [g_T][\dot{\theta}] + [C_T][\dot{\theta}] + [k_T][\theta] = [F_T]$$

where:

$[g_T]$ = Torsional relative damping matrix (includes the internal or hysteretic structural damping in the shafting).

$[k_T]$ = Torsional stiffness matrix.

$[C_T]$ = Damping matrix due to the viscous damping of the propeller blade.

$[\theta]$ = Twist of shaft at each node

$[F_T]$ = Torque on propeller

Solution to the Equation of Motion:

1. Solve free vibration problem to obtain the natural frequencies and subsequent eigen vectors (mode shapes).
2. Each column of the modal matrix [P] is an eigen vector (mode shape).

$$[P][Y] = [\theta]$$

3. Substituting [P][Y] for [Θ] and premultiplying by $[P]^T$ decouples the equations and results in three independent second order differential equations.

$$\ddot{Y}1 + 2(\zeta_1 + \zeta_2)W_1\dot{Y}_1 + W_1^2Y_1 = C_1M_t$$

$$\ddot{Y}_2 + 2\zeta_1W_2\dot{Y}_2 + W_2^2Y_2 = C_2M_t$$

$$\ddot{Y}_3 + 2\zeta_1W_3\dot{Y}_3 + W_3^2Y_3 = C_3M_t$$

ζ_1 = Shaft damping ratio   W: = natural frequency
ζ_2 = Propeller damping ratio   for mode

Any torque M_t can be input, and the solution to each equation can be solved using Runge-Kutta method of fourth order.

To determine rotation:

$$[\Theta] = [P][Y]$$

To determine torque on the intermediate shaft:

$$T = \sqrt{[(k_1)(\Theta_2 - \Theta_1)^2 + w_1g_1\ (\Theta_2 - \Theta_1)^2]} \approx k_1\ (\Theta_2 - \Theta_1)$$

The damping due to the propeller blade and shafting is varied until the torque wave form calculated agrees with that measured on the shaft.

Approximations

1. $[P]^T[C_T][P] = \begin{vmatrix} A & 0 & 0 \\ 0 & 0 & 0 \end{vmatrix}$

   Where A = Constant

2. Shaft is fixed for torsion at the flywheel.

3. $k_1 + W_1g_1 \approx k_1$

LONGITUDINAL MODEL (See Figure 6)

List of Parameters

Location	M kg	K N/m
1	7000	9.71×10^8
2	8800	9.71×10^8
3	5600	9.71×10^8

Equations of Motion:

$$[M][\ddot{X}] + [g_L][\dot{X}] + [C_L][\dot{X}] + [k_L][X] = [F_L]$$

Solution to the Equation of Motion:

Same method as torsional model resulting in the following equations:

$$\ddot{Y}_1 + 2(\zeta_1 + \zeta_2)W_1\dot{Y}_1 + W_1^2 Y_1 = C_1F_t$$

$$\ddot{Y}_2 + 2\zeta_1 W_2\dot{Y}_2 + W_2^2 Y_2 = C_2F_t$$

$$\ddot{Y}_3 + 2\zeta_1 W_3\dot{Y}_3 + W_3^2 Y_3 = C_3F_t$$

ζ_1 = Shaft damping ratio W = Natural Frequency for mode
ζ_2 = Propeller damping ratio

Any thrust F_t can be input, and the solution to each equation can be solved using Runge-Kutta method order four.

To determine movement of shaft:

$$[X] = [P][Y]$$

To determine thrust on the intermediate shaft:

$$F = \sqrt{[((K_3)(-X_3))^2 + ((\dot{X}_3)(g_3))^2]} \approx (K_3)(-X_3)$$

The damping due to the propeller blade and shafting is varied until the thrust wave form calculated agrees with that measured on the shaft.

Approximations

1. $[P]^T[C_L][P] = \begin{vmatrix} A & 0 & 0 \\ 0 & 0 & 0 \end{vmatrix}$

   Where: A = Constant

2. Shaft is fixed at gear box.

3. $X_3K_3 + \dot{X}_3g_3 \approx X_3K_3$

APPENDIX H

SHAFT TORSIONAL AND LONGITUDINAL SOFTWARE PROGRAMS

SOURCE: CANMAR

TABLE OF CONTENTS

TORQUE 1

THRUST 7

```
10    ! PROGRAM "TORQUE" BY D.N. BRUCE COWPER 85-03-13
20    ! THE EQUATION OF MOTION FOR THE TORQUE OF THE PROPULSION TRAIN
30    ! OF THE ROBERT LEMEUR IS SLOVED, USING THE MODAL SUPERPOSITION
40    ! METHOD AND THE RUNGE-KUTTA FOURTH ORDER METHOD.
50    ! THERE ARE THREE DEGREES OF FREEDOM IN THE SIMPLIFIED MODEL.
60    !
70    ! THE EQUAION OF MOTION IS: [J](a)+[Ct](w)+[G](w)+[K](o)=(F)
80    !
90    ! [J] IS THE MASS POLAR MOMENT OF INERTIA MATRIX
100   ! [G] IS THE DAMPING MATRIX (PROPORTIONAL TO THE STIFFNESS MATRIX [K])
110   ! [Ct] IS THE PROPELLER DAMPING MATRIX
120   ! [K] IS THE STIFFNESS MATRIX
130   ! (a) IS THE ANGULAR ACCELERATION MATRIX
140   ! (w) IS THE ANGULAR VELOCITY MATRIX
150   ! (o) IS THE ANGULAR DISPLACEMENT MATRIX
160   ! (F) IS THE FORCING FUNCTION MATRIX (ie. TORQUE ON PROPELLER)
170   !
180   !
190 Start:  !
200   OPTION BASE 1
210   DEG
220   REAL T(4),Y(4),X(4),F(4)
230   REAL Tt(3000,3),Yy(3000,3),Zz(3000,3),M(3000)
240   REAL Theta1(3000),Theta2(3000),Theta3(3000),Torque(3000)
250   DIM Title$[25]
260   !
270   K1=5.81E5              !TORSIONAL STIFFNESS OF SHAFTING AT GAUGES (NM/RAD)
280   W1=509                   !FIRST NATURAL FREQUENCY SQUARED (RAD/SEC)^2
290   W2=7639                  !SECOND NATURAL FREQUENCY SQUARED (RAD/SEC)^2
300   W3=70735                 !THIRD NATURAL FREQUENCY SQUARED (RAD/SEC)^2
310   !
320 Main:  !
330   PRINTER IS 16
340   PRINT PAGE
350   GOSUB Input_data
360   GOSUB Runge_kutta
370   BEEP
380   BEEP
390   GOSUB Solution
400   GOSUB Plot_modes
410   GOSUB Plot_solution
420   PRINT PAGE
430   PRINT LIN(10)
440   Q$=""
450   INPUT "DO YOU WANT TO RUN ANOTHER CASE?(Y,N)",Q$
460   IF Q$="Y" THEN GOTO Start
470   PRINT "*********************************************"
480   PRINT "          FINISHED PROGRAM"
490   PRINT "*********************************************"
500   STOP
510   END
520   !
530 Input_data:  !
540   INPUT "INPUT THE DATE (YY/MM/DD/)",Date$
550   INPUT "INPUT THE TEST NUMBER ",Test$
560   INPUT "INPUT THE TIME INCREMENT (.01-.001) ",H
570   INPUT "INPUT THE NUMBER OF TIME INCREMENTS (10-3000)",Points
580   INPUT "INPUT THE DAMPING RATIO FOR THE PROPELLER  (0-1)",Dp
590   INPUT "INPUT THE DAMPING RATIO FOR THE SHAFT (0-1)",Ds
600   INPUT "ENTER TYPE OF SIGNAL FOR INPUT FORCING FUNCTION (S-SINE,SQ-SQUARE,T
-TRIANGLE)",Input_type$
610   INPUT "INPUT THE TIME OF FIRST IMPULSE",Ti
620   INPUT "INPUT THE LENGTH OF FIRST IMPULSE AND MAXIMUM VALUE (SEC.,KNm) ",Lt
i,M1
630   INPUT "INPUT THE TIME OF SECOND IMPULSE",Ti1
640   INPUT "INPUT THE LENGTH OF SECOND IMPULSE AND MAXIMUM VALUE (SEC.,KNm),",L
```

```
ti1,M2
650    INPUT "INPUT THE TIME OF THIRD IMPULSE",Ti2
660    INPUT "INPUT THE LENGTH OF THIRD IMPULSE AND MAXIMUM VALUE (SEC.,KNM)",Lti
2,M3
670    INPUT "INPUT THE TIME OF FOURTH IMPULSE",Ti3
680    INPUT "INPUT THE LENGTH OF FOURTH IMPULSE AND MAXIMUM VALUE (SEC.,KNM)",Lt
i3,M4
690    INPUT "INPUT THE TIME OF FIFTH IMPULSE",Ti4
700    INPUT "INPUT THE LENGTH OF FIFTH IMPULSE AND MAXIMUM VALUE (SEC.,KNM)",Lti
4,M5
710    INPUT "INPUT THE TIME OF SIXTH IMPULSE",Ti5
720    INPUT "INPUT THE LENGTH OF SIXTH IMPULSE AND MAXIMUM VALUE (SEC.,KNM)",Lti
5,M6
730    INPUT "INPUT THE TIME OF SEVENTH IMPULSE",Ti6
740    INPUT "INPUT THE LENGTH OF SEVENTH IMPULSE AND MAXIMUM VALUE (SEC.,KNM)",L
ti6,M7
750    !
760    RETURN
770 Runge_kutta:  !
780    DISP "INTEGRATING DIFFERENTIAL EQUATIONS"
790    FOR K=1 TO 3
800      FOR J=1 TO Points-1
810        IF J=1 THEN
820          I=1
830          T(1)=Tt(1,K)=0
840          Yy(1,K)=0
850          Zz(1,K)=0
860          Y(1)=0
870          X(1)=0
880          GOSUB Load_time
890          IF K=1 THEN F(1)=FNF1(X(1),Y(1),M(J))
900          IF K=2 THEN F(1)=FNF2(X(1),Y(1),M(J))
910          IF K=3 THEN F(1)=FNF3(X(1),Y(1),M(J))
920        ELSE
930          I=1
940          T(1)=Tt(J,K)
950          X(1)=Yy(J,K)
960          Y(1)=Zz(J,K)
970          GOSUB Load_time
980          IF K=1 THEN F(1)=FNF1(X(1),Y(1),M(J))
990          IF K=2 THEN F(1)=FNF2(X(1),Y(1),M(J))
1000         IF K=3 THEN F(1)=FNF3(X(1),Y(1),M(J))
1010       END IF
1020   !
1030       FOR I=2 TO 4
1040         IF I=4 THEH.Mult=2
1050         IF (I=2) OR (I=3) THEN Mult=1
1060         T(I)=Tt(J,K)+H*.5*Mult
1070         X(I)=Yy(J,K)+Y(I-1)*H*.5*Mult
1080         Y(I)=Zz(J,K)+F(I-1)*H*.5*Mult
1090         GOSUB Load_time
1100         IF K=1 THEN F(I)=FNF1(X(I),Y(I),M(J))
1110         IF K=2 THEN F(I)=FNF2(X(I),Y(I),M(J))
1120         IF K=3 THEN F(I)=FNF3(X(I),Y(I),M(J))
1130       NEXT I
1140   !
1150       Yy(J+1,K)=Yy(J,K)+H/6*(Y(1)+2*Y(2)+2*Y(3)+Y(4))
1160       Zz(J+1,K)=Zz(J,K)+H/6*(F(1)+2*F(2)+2*F(3)+F(4))
1170       Tt(J+1,K)=T(4)
1180     NEXT J
1190   NEXT K
1200   DISP "FINISHED INTEGRATING"
1210   !
1220 Equations: !
1230   ! EQUATIONS OF MOTION FOR MODAL SUPERPOSITION
1240   !
```

```
1250  DEF FNF1(X,Y,M)=1.209E-3*M-2*(Dp+Ds)*SQR(W1)*Y-W1*X      !FIRST MODE EQUAT
ION
1260  DEF FNF2(X,Y,M)=-1.346E-3*M-2*Ds*SQR(W2)*Y-W2*X            !SECOND MODE EQUA
TION
1270  DEF FNF3(X,Y,M)=1.366E-4*M-2*Ds*SQR(W3)*Y-W3*X             !THIRD MODE EQUAT
ION
1280  RETURN
1290  !
1300 Load_time: ! TORQUE ON PROPELLER BLADE AS A FUNCTION OF TIME
1310  ! M=TORQUE ON PROPELLER BLADE IN Nm
1320  ! T(I)= TIME IN SECONDS
1330  !
1340  M(J)=0
1350  IF Input_type$="S" THEN
1360     IF (Ti<>0) AND (T(I)>=Ti) AND (T(I)<=Ti+Lti) THEN M(J)=M1*SIN((T(I)-Ti)/
(Lti*2)*360)
1370     IF (Ti1<>0) AND (T(I)>=Ti1) AND (T(I)<=Ti1+Lti1) THEN M(J)=M2*SIN((T(I)-
Ti1)/(Lti1*2)*360)
1380     IF (Ti2<>0) AND (T(I)>=Ti2) AND (T(I)<=Ti2+Lti2) THEN M(J)=M3*SIN((T(I)-
Ti2)/(Lti2*2)*360)
1390     IF (Ti3<>0) AND (T(I)>=Ti3) AND (T(I)<=Ti3+Lti3) THEN M(J)=M4*SIN((T(I)-
Ti3)/(Lti3*2)*360)
1400     IF (Ti4<>0) AND (T(I)>=Ti4) AND (T(I)<=Ti4+Lti4) THEN M(J)=M5*SIN((T(I)-
Ti4)/(Lti4*2)*360)
1410     IF (Ti5<>0) AND (T(I)>=Ti5) AND (T(I)<=Ti5+Lti5) THEN M(J)=M6*SIN((T(I)-
Ti5)/(Lti5*2)*360)
1420  END IF
1430  IF Input_type$="SQ" THEN
1440     IF (T(I)>=Ti) AND (T(I)<=Ti+Lti) THEN M(J)=M1
1450     IF (T(I)>=Ti1) AND (T(I)<=Ti1+Lti1) THEN M(J)=M2
1460     IF (T(I)>=Ti2) AND (T(I)<=Ti2+Lti2) THEN M(J)=M3
1470     IF (T(I)>=Ti3) AND (T(I)<=Ti3+Lti3) THEN M(J)=M4
1480     IF (T(I)>=Ti4) AND (T(I)<=Ti4+Lti4) THEN M(J)=M5
1490     IF (T(I)>=Ti5) AND (T(I)<=Ti5+Lti5) THEN M(J)=M6
1500  END IF
1510  IF Input_type$="T" THEN
1520   ! IF (T(I)>=Ti) AND (T(I)<=Ti+.5*Lti) THEN M(J)=M1*(T(I)-Ti)/(Lti*.5)
1530   ! IF (T(I)>Ti+.5*Lti) AND (T(I)<=Ti+Lti) THEN M(J)=M1-M1*(T(I)-(Ti+.5*Lti
))/(Lti*.5)
1540     IF (T(I)>=Ti) AND (T(I)<=Ti+Lti) THEN M(J)=M1
1550     IF (Ti1<>0) AND (T(I)>=Ti1) AND (T(I)<=Ti1+.5*Lti1) THEN M(J)=M2*(T(I)-T
i1)/(Lti1*.5)
1560     IF (Ti1<>0) AND (T(I)>Ti1+.5*Lti1) AND (T(I)<=Ti1+Lti1) THEN M(J)=M2-M2*
(T(I)-(Ti1+.5*Lti1))/(Lti1*.5)
1570     IF (Ti2<>0) AND (T(I)>=Ti2) AND (T(I)<=Ti2+.5*Lti2) THEN M(J)=M3*(T(I)-T
i2)/(Lti2*.5)
1580     IF (Ti2<>0) AND (T(I)>Ti2+.5*Lti2) AND (T(I)<=Ti2+Lti2) THEN M(J)=M3-M3*
(T(I)-(Ti2+.5*Lti2))/(Lti2*.5)
1590     IF (Ti3<>0) AND (T(I)>=Ti3) AND (T(I)<=Ti3+.5*Lti3) THEN M(J)=M4*(T(I)-T
i3)/(Lti3*.5)
1600     IF (Ti3<>0) AND (T(I)>Ti3+.5*Lti3) AND (T(I)<=Ti3+Lti3) THEN M(J)=M4-M4*
(T(I)-(Ti3+.5*Lti3))/(Lti3*.5)
1610     IF (Ti4<>0) AND (T(I)>=Ti4) AND (T(I)<=Ti4+.5*Lti4) THEN M(J)=M5*(T(I)-T
i4)/(Lti4*.5)
1620     IF (Ti4<>0) AND (T(I)>Ti4+.5*Lti4) AND (T(I)<=Ti4+Lti4) THEN M(J)=M5-M5*
(T(I)-(Ti4+.5*Lti4))/(Lti4*.5)
1630     IF (Ti5<>0) AND (T(I)>=Ti5) AND (T(I)<=Ti5+.5*Lti5) THEN M(J)=M6*(T(I)-T
i5)/(Lti5*.5)
1640     IF (Ti5<>0) AND (T(I)>Ti5+.5*Lti5) AND (T(I)<=Ti5+Lti5) THEN M(J)=M6-M6*
(T(I)-(Ti5+.5*Lti5))/(Lti5*.5)
1650     IF (Ti6<>0) AND (T(I)>=Ti6) AND (T(I)<=Ti6+.5*Lti6) THEN M(J)=M7*(T(I)-T
i6)/(Lti6*.5)
1660     IF (Ti6<>0) AND (T(I)>Ti6+.5*Lti6) AND (T(I)<=Ti6+Lti6) THEN M(J)=M7-M7*
(T(I)-(Ti6+.5*Lti6))/(Lti6*.5)
1670  END IF
1680  M(J)=M(J)*1000
```

```
1690  RETURN
1700  !
1710 Plot_modes: !
1720  PRINT "PLOTS OF MODE SHAPES"
1730  PLOTTER IS "GRAPHICS"
1740  GRAPHICS
1750  K1=0
1760  INPUT "ENTER MODE SHAPE TO BE PLOTTED (1,2,3) OR PUSH CONT ",K1
1770  IF K1=0 THEN RETURN
1780  K=1
1790  GOSUB Plot_setup
1800    !
1810  MOVE Tt(1,K1),Yy(1,K1)
1820  FOR I=2 TO Points
1830    PLOT Tt(I,K1),Yy(I,K1),-1
1840  NEXT I
1850  MOVE .60*(Xmax-Xmin),.60*Ymax
1860  LABEL "Y"&VAL$(K1)
1870  PAUSE
1880  DISP "PUSH CONT"
1890  DISP ""
1900  Q$=""
1910  INPUT "DO YOU WANT TO DUMP THESE GRAPHS ?(Y,N)",Q$
1920  IF Q$="Y" THEN
1930    PRINTER IS 0
1940    PRINT LIN(3)
1950    PRINT "PLOTS OF MODAL RESPONSE FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM"
1960    PRINT LIN(3)
1970    DUMP GRAPHICS
1980    EXIT GRAPHICS
1990    PRINT PAGE
2000    PRINTER IS 16
2010  ELSE
2020    EXIT GRAPHICS
2030  END IF
2040  Q$=""
2050  INPUT "DO YOU WANT TO PLOT ANOTHER MODE?(Y,N)",Q$
2060  IF Q$="Y" THEN GOTO Plot_modes
2070  RETURN
2080  !
2090 Plot_solution: !
2100  PRINT PAGE
2110  PRINT "PLOTS OF TORQUE VS TIME"
2120  PLOTTER IS "GRAPHICS"
2130  GRAPHICS
2140  FOR K=1 TO 2
2150    Title$="PROP. TWIST (RAD.)"
2160    IF K=1 THEN Title$="PROPELLER TORQUE (KNm)"
2170    IF K=2 THEN Title$="SHAFT TORQUE (KNm)"
2180    IF K=1 THEN
2190      Xmin=0
2200      Xmax=.80
2210      Ymin=-300
2220      Ymax=300
2230    END IF
2240    IF K=2 THEN
2250      Ymin=-150
2260      Ymax=150
2270    END IF
2280    GOSUB Plot_setup
2290    MOVE Tt(1,1),Theta1(1)
2300    FOR I=2 TO Points
2310      IF K=1 THEN PLOT Tt(I,1),M(I)*.001,-1
2320      IF K=2 THEN PLOT Tt(I,1),Torque(I),-1
2330    NEXT I
2340    MOVE .5*(Xmax+Xmin),.98*Ymax
```

```
2350    LABEL Title$
2360    DISP "PUSH CONT"
2370    PAUSE
2380    DISP ""
2390  NEXT K
2400  Q$=""
2410  INPUT "DO YOU WANT TO PLOT THESE GRAPHS AGAIN?(Y,N)",Q$
2420  IF Q$="Y" THEN GOTO Plot_solution
2430  Q$=""
2440  INPUT "DO YOU WANT TO DUMP THESE GRAPHS ?(Y,N)",Q$
2450 ! EXIT GRAPHICS
2460  IF Q$="Y" THEN
2470    PRINTER IS 0
2480    PRINT LIN(5)
2490    PRINT "PLOTS OF TORQUE  FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM MODEL"
2500    PRINT LIN(2)
2510    PRINT "TEST "&Test$
2520    PRINT "ANALYSIS DATE: "&Date$
2530    PRINT LIN(2)
2540    DUMP GRAPHICS
2550    PRINT PAGE
2560    PRINT "PLOTS OF TORQUE  FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM MODEL"
2570    PRINT LIN(2)
2580    PRINT "TEST "&Test$
2590    PRINT "ANALYSIS DATE: "&Date$
2600    PRINT LIN(2)
2610    PRINT "DAMPING RATIO  FOR THE SHAFT:      ";Ds
2620    PRINT "DAMPING RATIO  FOR THE PROPELLER: ";Dp
2630    PRINT "TIME INCREMENT (SEC.):             ";H
2640    PRINT "TIME AT FIRST IMPULSE (SEC.):      ";Ti
2650    PRINT "LENGTH OF FIRST IMPULSE (SEC.):    ";Lti;"   MAX. TORQUE (KNm): ";
M1
2660    IF Ti1<>0 THEN PRINT "TIME AT SECOND IMPULSE (SEC.):     ";Ti1
2670    IF Ti1<>0 THEN PRINT "LENGTH OF SECOND IMPULSE (SEC.):  ";Lti1;"   MAX.
TORQUE (KNm): ";M2
2680    IF Ti2<>0 THEN PRINT "TIME AT THIRD IMPULSE (SEC.):      ";Ti2
2690    IF Ti2<>0 THEN PRINT "LENGTH OF THIRD IMPULSE (SEC.):   ";Lti2;"   MAX.
TORQUE (KNm): ";M3
2700    IF Ti3<>0 THEN PRINT "TIME AT FOURTH IMPULSE (SEC.):      ";Ti3
2710    IF Ti3<>0 THEN PRINT "LENGTH OF FOURTH IMPULSE (SEC.):   ";Lti3;"   MAX.
 TORQUE (KNm): ";M4
2720    IF Ti4<>0 THEN PRINT "TIME AT FIFTH IMPULSE (SEC.):      ";Ti4
2730    IF Ti4<>0 THEN PRINT "LENGTH OF FIFTH IMPULSE (SEC.):   ";Lti4;"   MAX.
TORQUE (KNm): ";M5
2740    IF Ti5<>0 THEN PRINT "TIME AT SIXTH IMPULSE (SEC.):      ";Ti5
2750    IF Ti5<>0 THEN PRINT "LENGTH OF SIXTH IMPULSE (SEC.):   ";Lti5;"   MAX.
TORQUE (KNm): ";M6
2760    IF Ti6<>0 THEN PRINT "TIME AT SEVENTH IMPULSE (SEC.):      ";Ti6
2770    IF Ti6<>0 THEN PRINT "LENGTH OF SEVENTH IMPULSE (SEC.):   ";Lti6;"   MAX
. TORQUE (KNm): ";M7
2780    PRINT PAGE
2790    PRINTER IS 16
2800  END IF
2810  RETURN
2820  !
2830 Solution: !

2840  DISP "CALCULATING TWIST AND TORQUE"
2850  FOR I=1 TO Points
2860    Theta1(I)=1.751*Yy(I,1)-.226*Yy(I,2)+2.157E-5*Yy(I,3)
2870    Theta2(I)=1.117*Yy(I,1)+1.0034*Yy(I,2)-1.063E-3*Yy(I,3)
2880    Theta3(I)=.0240*Yy(I,1)+.0240*Yy(I,2)+.0240*Yy(I,3)
2890    Torque(I)=K1*(Theta1(I)-Theta2(I))*.001   !SHAFT TORQUE IN KNm
2900  NEXT I
2910  DISP ""
2920  RETURN
```

```
2930  !
2940 Plot_setup: !
2950  LOCATE 20,120,10+(K-1)*50,50+(K-1)*50
2960  FRAME
2970  MOVE 40,0
2980  LABEL "TIME (Seconds)"
2990  INPUT "INPUT SCALE (XMIN,XMAX,YMIN,YMAX)",Xmin,Xmax,Ymin,Ymax
3000  SCALE Xmin,Xmax,Ymin,Ymax
3010  AXES Xmax/50,Ymax/10,Xmin,Ymin,5,2
3020  AXES Xmax/50,Ymax/10,Xmin,Ymax,5,2
3030  AXES Xmax/50,Ymax/10,Xmax,Ymin,5,2
3040  FIXED 2
3050  LORG 5
3060  X=Xmin
3070  Y=Ymin
3080  IF K=1 THEN
3090    FOR I=1 TO 10
3100      X=X+ABS(Xmax-Xmin)/10
3110      X$=VAL$(X)
3120      MOVE X,Ymin-.07*ABS(Ymax-Ymin)
3130      LABEL X$
3140    NEXT I
3150  END IF
3160    !
3170  LORG 8
3180  FIXED 0
3190  FOR I=1 TO 5
3200    Y$=VAL$(Y)
3210    MOVE Xmin,Y
3220    LABEL Y$&"  "
3230    Y=Y+ABS(Ymax-Ymin)/5
3240  NEXT I
3250  STANDARD
3260  RETURN
```

```
10     ! PROGRAM "THRUST" BY D.N. BRUCE COWPER 85-03-13
20     ! THE EQUATION OF MOTION FOR THE THRUST OF THE PROPULSION TRAIN
30     ! OF THE ROBERT LEMEUR IS SLOVED, USING THE MODAL SUPERPOSITION
40     ! METHOD AND THE RUNGE-KUTTA FOURTH ORDER METHOD.
50     ! THERE ARE THREE DEGREES OF FREEDOM IN THE SIMPLIFIED MODEL.
60     !
70     ! THE EQUAION OF MOTION IS: [M](a)+[C1](v)+[G](v)+[K](X)=(FL)
80     !
90     ! [M] IS THE MASS POLAR MOMENT OF INERTIA MATRIX
100    ! [G] IS THE DAMPING MATRIX (PROPORTIONAL TO THE STIFFNESS MATRIX [K])
110    ! [C1] IS THE PROPELLER DAMPING MATRIX
120    ! [K] IS THE STIFFNESS MATRIX
130    ! (a) IS THE ~~ANGULAR~~ ACCELERATION MATRIX
140    ! (v) IS THE ~~ANGULAR~~ VELOCITY MATRIX
150    ! (X) IS THE ~~ANGULAR~~ DISPLACEMENT MATRIX
160    ! (F1) IS THE FORCING FUNCTION MATRIX (ie.THRUST ON PROPELLLER)
170    !
180    !
190 Start:  !
200   OPTION BASE 1
210   DEG
220   REAL T(4),Y(4),X(4),F(4)
230   REAL Tt(3000,3),Yy(3000,3),Zz(3000,3),M(3000)
240   REAL Theta1(3000),Theta2(3000),Theta3(3000),Torque(3000)
250   DIM Title$[25]
260   !
270   K1=9.71E8        !LONGITUDINAL  STIFFNESS OF SHAFTING AT GAUGES (N/m)
280   W1=25684                  !FIRST NATURAL FREQUENCY SQUARED (RAD/SEC)^2
290   W2=228484                 !SECOND NATURAL FREQUENCY SQUARED (RAD/SEC)^2
300   W3=451584                 !THIRD NATURAL FREQUENCY SQUARED (RAD/SEC)^2
310   !
320 Main:  !
330   PRINTER IS 16
340   PRINT PAGE
350   GOSUB Input_data
360   GOSUB Runge_kutta
370   BEEP
380   BEEP
390   GOSUB Solution
400   GOSUB Plot_modes
410   GOSUB Plot_solution
420   PRINT PAGE
430   PRINT LIN(10)
440   Q$=""
450   INPUT "DO YOU WANT TO RUN ANOTHER CASE?(Y,N)",Q$
460   IF Q$="Y" THEN GOTO Start
470   PRINT "********************************************"
480   PRINT "          FINISHED PROGRAM"
490   PRINT "********************************************"
500   STOP
510   END
520   !
530 Input_data:  !
540   INPUT "INPUT THE DATE (YY/MM/DD/)",Date$
550   INPUT "INPUT THE TEST NUMBER ",Test$
560   INPUT "INPUT THE TIME INCREMENT (.01-.001) ",H
570   INPUT "INPUT THE NUMBER OF TIME INCREMENTS (10-3000)",Points
580   INPUT "INPUT THE DAMPING RATIO FOR THE PROPELLER  (0-1)",Dp
590   INPUT "INPUT THE DAMPING RATIO FOR THE SHAFT (0-1)",Ds
600   INPUT "ENTER TYPE OF SIGNAL FOR INPUT FORCING FUNCTION (S-SINE,SQ-SQUARE,T
-TRIANGLE)",Input_type$
610   INPUT "INPUT THE TIME OF FIRST IMPULSE",Ti
620   INPUT "INPUT THE LENGTH OF FIRST IMPULSE AND MAXIMUM VALUE (SEC.,KNm) ",Lt
i,M1
630   INPUT "INPUT THE TIME OF SECOND IMPULSE",Ti1
```

```
640   INPUT "INPUT THE LENGTH OF SECOND IMPULSE AND MAXIMUM VALUE (SEC.,KNm),",L
ti1,M2
650   INPUT "INPUT THE TIME OF THIRD IMPULSE",Ti2
660   INPUT "INPUT THE LENGTH OF THIRD IMPULSE AND MAXIMUM VALUE (SEC.,KNM)",Lti
2,M3
670   INPUT "INPUT THE TIME OF FOURTH IMPULSE",Ti3
680   INPUT "INPUT THE LENGTH OF FOURTH IMPULSE AND MAXIMUM VALUE (SEC.,KNM)",Lt
i3,M4
690   INPUT "INPUT THE TIME OF FIFTH IMPULSE",Ti4
700   INPUT "INPUT THE LENGTH OF FIFTH IMPULSE AND MAXIMUM VALUE (SEC.,KNM)",Lti
4,M5
710   INPUT "INPUT THE TIME OF SIXTH IMPULSE",Ti5
720   INPUT "INPUT THE LENGTH OF SIXTH IMPULSE AND MAXIMUM VALUE (SEC.,KNM)",Lti
5,M6
730   INPUT "INPUT THE TIME OF SEVENTH IMPULSE",Ti6
740   INPUT "INPUT THE LENGTH OF SEVENTH IMPULSE AND MAXIMUM VALUE (SEC.,KNM)",L
ti6,M7
750   !
760   RETURN
770 Runge_kutta:  !
780   DISP "INTEGRATING DIFFERENTIAL EQUATIONS"
790   FOR K=1 TO 3
800     FOR J=1 TO Points-1
810       IF J=1 THEN
820         I=1
830         T(1)=Tt(1,K)=0
840         Yy(1,K)=0
850         Zz(1,K)=0
860         Y(1)=0
870         X(1)=0
880         GOSUB Load_time
890         IF K=1 THEN F(1)=FNF1(X(1),Y(1),M(J))
900         IF K=2 THEN F(1)=FNF2(X(1),Y(1),M(J))
910         IF K=3 THEN F(1)=FNF3(X(1),Y(1),M(J))
920       ELSE
930         I=1
940         T(1)=Tt(J,K)
950         X(1)=Yy(J,K)
960         Y(1)=Zz(J,K)
970         GOSUB Load_time
980         IF K=1 THEN F(1)=FNF1(X(1),Y(1),M(J))
990         IF K=2 THEN F(1)=FNF2(X(1),Y(1),M(J))
1000        IF K=3 THEN F(1)=FNF3(X(1),Y(1),M(J))
1010      END IF
1020  !
1030      FOR I=2 TO 4
1040        IF I=4 THEN Mult=2
1050        IF (I=2) OR (I=3) THEN Mult=1
1060        T(I)=Tt(J,K)+H*.5*Mult
1070        X(I)=Yy(J,K)+Y(I-1)*H*.5*Mult
1080        Y(I)=Zz(J,K)+F(I-1)*H*.5*Mult
1090        GOSUB Load_time
1100        IF K=1 THEN F(I)=FNF1(X(I),Y(I),M(J))
1110        IF K=2 THEN F(I)=FNF2(X(I),Y(I),M(J))
1120        IF K=3 THEN F(I)=FNF3(X(I),Y(I),M(J))
1130      NEXT I
1140  !
1150      Yy(J+1,K)=Yy(J,K)+H/6*(Y(1)+2*Y(2)+2*Y(3)+Y(4))
1160      Zz(J+1,K)=Zz(J,K)+H/6*(F(1)+2*F(2)+2*F(3)+F(4))
1170      Tt(J+1,K)=T(4)
1180    NEXT J
1190  NEXT K
1200  DISP "FINISHED INTEGRATING"
1210  !
1220 Equations: !
1230  ! EQUATIONS OF MOTION FOR MODAL SUPERPOSITION
```

```
1240  !
1250  DEF FNF1(X,Y,M)=M/13930-2*(Dp+Ds)*SQR(W1)*Y-W1*X
1260  DEF FNF2(X,Y,M)=-.462/3367*M-2*Ds*SQR(W2)*Y-W2*X
1270  DEF FNF3(X,Y,M)=.1182/1807*M-2*Ds*SQR(W3)*Y-W3*X
1280  RETURN
1290  !
1300 Load_time: ! TORQUE ON PROPELLER BLADE AS A FUNCTION OF TIME
1310  ! M=TORQUE ON PROPELLER BLADE IN Nm
1320  ! T(I)= TIME IN SECONDS
1330  !
1340  M(J)=0
1350  IF Input_type$="S" THEN
1360    IF (Ti<>0) AND (T(I)>=Ti) AND (T(I)<=Ti+Lti) THEN M(J)=M1*SIN((T(I)-Ti)/
(Lti*2)*360)
1370    IF (Ti1<>0) AND (T(I)>=Ti1) AND (T(I)<=Ti1+Lti1) THEN M(J)=M2*SIN((T(I)-
Ti1)/(Lti1*2)*360)
1380    IF (Ti2<>0) AND (T(I)>=Ti2) AND (T(I)<=Ti2+Lti2) THEN M(J)=M3*SIN((T(I)-
Ti2)/(Lti2*2)*360)
1390    IF (Ti3<>0) AND (T(I)>=Ti3) AND (T(I)<=Ti3+Lti3) THEN M(J)=M4*SIN((T(I)-
Ti3)/(Lti3*2)*360)
1400    IF (Ti4<>0) AND (T(I)>=Ti4) AND (T(I)<=Ti4+Lti4) THEN M(J)=M5*SIN((T(I)-
Ti4)/(Lti4*2)*360)
1410    IF (Ti5<>0) AND (T(I)>=Ti5) AND (T(I)<=Ti5+Lti5) THEN M(J)=M6*SIN((T(I)-
Ti5)/(Lti5*2)*360)
1420  END IF
1430  IF Input_type$="SQ" THEN
1440    IF (T(I)>=Ti) AND (T(I)<=Ti+Lti) THEN M(J)=M1
1450    IF (T(I)>=Ti1) AND (T(I)<=Ti1+Lti1) THEN M(J)=M2
1460    IF (T(I)>=Ti2) AND (T(I)<=Ti2+Lti2) THEN M(J)=M3
1470    IF (T(I)>=Ti3) AND (T(I)<=Ti3+Lti3) THEN M(J)=M4
1480    IF (T(I)>=Ti4) AND (T(I)<=Ti4+Lti4) THEN M(J)=M5
1490    IF (T(I)>=Ti5) AND (T(I)<=Ti5+Lti5) THEN M(J)=M6
1500  END IF
1510  IF Input_type$="T" THEN
1520    IF (T(I)>=Ti) AND (T(I)<=Ti+.5*Lti) THEN M(J)=M1*(T(I)-Ti)/(Lti*.5)
1530    IF (T(I)>Ti+.5*Lti) AND (T(I)<=Ti+Lti) THEN M(J)=M1-M1*(T(I)-(Ti+.5*Lti)
)/(Lti*.5)
1540  ! IF (T(I)>=Ti) AND (T(I)<=Ti+Lti) THEN M(J)=M1
1550    IF (Ti1<>0) AND (T(I)>=Ti1) AND (T(I)<=Ti1+.5*Lti1) THEN M(J)=M2*(T(I)-T
i1)/(Lti1*.5)
1560    IF (Ti1<>0) AND (T(I)>Ti1+.5*Lti1) AND (T(I)<=Ti1+Lti1) THEN M(J)=M2-M2*
(T(I)-(Ti1+.5*Lti1))/(Lti1*.5)
1570    IF (Ti2<>0) AND (T(I)>=Ti2) AND (T(I)<=Ti2+.5*Lti2) THEN M(J)=M3*(T(I)-T
i2)/(Lti2*.5)
1580    IF (Ti2<>0) AND (T(I)>Ti2+.5*Lti2) AND (T(I)<=Ti2+Lti2) THEN M(J)=M3-M3*
(T(I)-(Ti2+.5*Lti2))/(Lti2*.5)
1590    IF (Ti3<>0) AND (T(I)>=Ti3) AND (T(I)<=Ti3+.5*Lti3) THEN M(J)=M4*(T(I)-T
i3)/(Lti3*.5)
1600    IF (Ti3<>0) AND (T(I)>Ti3+.5*Lti3) AND (T(I)<=Ti3+Lti3) THEN M(J)=M4-M4*
(T(I)-(Ti3+.5*Lti3))/(Lti3*.5)
1610    IF (Ti4<>0) AND (T(I)>=Ti4) AND (T(I)<=Ti4+.5*Lti4) THEN M(J)=M5*(T(I)-T
i4)/(Lti4*.5)
1620    IF (Ti4<>0) AND (T(I)>Ti4+.5*Lti4) AND (T(I)<=Ti4+Lti4) THEN M(J)=M5-M5*
(T(I)-(Ti4+.5*Lti4))/(Lti4*.5)
1630    IF (Ti5<>0) AND (T(I)>=Ti5) AND (T(I)<=Ti5+.5*Lti5) THEN M(J)=M6*(T(I)-T
i5)/(Lti5*.5)
1640    IF (Ti5<>0) AND (T(I)>Ti5+.5*Lti5) AND (T(I)<=Ti5+Lti5) THEN M(J)=M6-M6*
(T(I)-(Ti5+.5*Lti5))/(Lti5*.5)
1650    IF (Ti6<>0) AND (T(I)>=Ti6) AND (T(I)<=Ti6+.5*Lti6) THEN M(J)=M7*(T(I)-T
i6)/(Lti6*.5)
1660    IF (Ti6<>0) AND (T(I)>Ti6+.5*Lti6) AND (T(I)<=Ti6+Lti6) THEN M(J)=M7-M7*
(T(I)-(Ti6+.5*Lti6))/(Lti6*.5)
1670  END IF
1680  M(J)=M(J)*1000
1690  RETURN
1700  !
```

```
1710 Plot_modes: !
1720  PRINT "PLOTS OF MODE SHAPES"
1730  PLOTTER IS "GRAPHICS"
1740  GRAPHICS
1750  K1=0
1760  INPUT "ENTER MODE SHAPE TO BE PLOTTED (1,2,3) OR PUSH CONT ",K1
1770  IF K1=0 THEN RETURN
1780  K=1
1790  GOSUB Plot_setup
1800    !
1810  MOVE Tt(1,K1),Yy(1,K1)
1820  FOR I=2 TO Points
1830    PLOT Tt(I,K1),Yy(I,K1),-1
1840  NEXT I
1850  MOVE .60*(Xmax-Xmin),.60*Ymax
1860  LABEL "Y"&VAL$(K1)
1870  PAUSE
1880  DISP "PUSH CONT"
1890  DISP ""
1900  Q$=""
1910  INPUT "DO YOU WANT TO DUMP THESE GRAPHS ?(Y,N)",Q$
1920  IF Q$="Y" THEN
1930    PRINTER IS 0
1940    PRINT LIN(3)
1950    PRINT "PLOTS OF MODAL RESPONSE FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM"
1960    PRINT LIN(3)
1970    DUMP GRAPHICS
1980    EXIT GRAPHICS
1990    PRINT PAGE
2000    PRINTER IS 16
2010  ELSE
2020    EXIT GRAPHICS
2030  END IF
2040  Q$=""
2050  INPUT "DO YOU WANT TO PLOT ANOTHER MODE?(Y,N)",Q$
2060  IF Q$="Y" THEN GOTO Plot_modes
2070  RETURN
2080  !
2090 Plot_solution: !
2100  PRINT PAGE
2110  PRINT "PLOTS OF THRUST VS TIME"
2120  PLOTTER IS "GRAPHICS"
2130  GRAPHICS
2140  FOR K=1 TO 2
2150    Title$="PROP. STRAIN "
2160    IF K=1 THEN Title$="PROPELLER THRUST (KN)"
2170    IF K=2 THEN Title$="SHAFT THRUST (KN)"
2180    IF K=1 THEN
2190      Xmin=0
2200      Xmax=.5
2210      Ymin=-500
2220      Ymax=500
2230    END IF
2240    IF K=2 THEN
2250      Ymin=-500
2260      Ymax=500
2270    END IF
2280    GOSUB Plot_setup
2290    MOVE Tt(1,1),Theta1(1)
2300    FOR I=2 TO Points
2310      IF K=1 THEN PLOT Tt(I,1),M(I)*.001,-1
2320      IF K=2 THEN PLOT Tt(I,1),Torque(I),-1
2330    NEXT I
2340    MOVE .5*(Xmax+Xmin),.90*Ymax
2350    LABEL Title$
2360    DISP "PUSH CONT"
```

```
2370     PAUSE
2380     DISP ""
2390   NEXT K
2400   Q$=""
2410   INPUT "DO YOU WANT TO PLOT THESE GRAPHS AGAIN?(Y,N)",Q$
2420   IF Q$="Y" THEN GOTO Plot_solution
2430   Q$=""
2440   INPUT "DO YOU WANT TO DUMP THESE GRAPHS ?(Y,N)",Q$
2450 ! EXIT GRAPHICS
2460   IF Q$="Y" THEN
2470     PRINTER IS 0
2480     PRINT LIN(5)
2490     PRINT "PLOTS OF THRUST  FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM MODEL"
2500     PRINT LIN(2)
2510     PRINT "TEST "&Test$
2520     PRINT "ANALYSIS DATE: "&Date$
2530     PRINT LIN(2)
2540     DUMP GRAPHICS
2550     PRINT PAGE
2560     PRINT "PLOTS OF THRUST  FOR M.V. ROBERT LEMEUR PROPULSION SYSTEM MODEL"
2570     PRINT LIN(2)
2580     PRINT "TEST "&Test$
2590     PRINT "ANALYSIS DATE: "&Date$
2600     PRINT LIN(2)
2610     PRINT "DAMPING RATIO  FOR THE SHAFT:      ";Ds
2620     PRINT "DAMPING RATIO  FOR THE PROPELLER: ";Dp
2630     PRINT "TIME INCREMENT (SEC.):            ";H
2640     PRINT "TIME AT FIRST IMPULSE (SEC.):     ";Ti
2650     PRINT "LENGTH OF FIRST IMPULSE (SEC.):   ";Lti;"   MAX. THRUST (KN): ";M
1
2660     IF Ti1<>0 THEN PRINT "TIME AT SECOND IMPULSE (SEC.):     ";Ti1
2670     IF Ti1<>0 THEN PRINT "LENGTH OF SECOND IMPULSE (SEC.):  ";Lti1;"   MAX.
THRUST (KN): ";M2
2680     IF Ti2<>0 THEN PRINT "TIME AT THIRD IMPULSE (SEC.):      ";Ti2
2690     IF Ti2<>0 THEN PRINT "LENGTH OF THIRD IMPULSE (SEC.):   ";Lti2;"   MAX.
THRUST (KN): ";M3
2700     IF Ti3<>0 THEN PRINT "TIME AT FOURTH IMPULSE (SEC.):     ";Ti3
2710     IF Ti3<>0 THEN PRINT "LENGTH OF FOURTH IMPULSE (SEC.):   ";Lti3;"   MAX.
 THRUST (KN): ";M4
2720     IF Ti4<>0 THEN PRINT "TIME AT FIFTH IMPULSE (SEC.):      ";Ti4
2730     IF Ti4<>0 THEN PRINT "LENGTH OF FIFTH IMPULSE (SEC.):   ";Lti4;"   MAX.
THRUST (KN): ";M5
2740     IF Ti5<>0 THEN PRINT "TIME AT SIXTH IMPULSE (SEC.):      ";Ti5
2750     IF Ti5<>0 THEN PRINT "LENGTH OF SIXTH IMPULSE (SEC.):   ";Lti5;"   MAX.
THRUST (KN): ";M6
2760     IF Ti6<>0 THEN PRINT "TIME AT SEVENTH IMPULSE (SEC.):     ";Ti6
2770     IF Ti6<>0 THEN PRINT "LENGTH OF SEVENTH IMPULSE (SEC.):   ";Lti6;"   MAX
. THRUST (KN): ";M7
2780     PRINT PAGE
2790     PRINTER IS 16
2800   END IF
2810   RETURN
2820   !
2830 Solution: !

2840   DISP "CALCULATING TWIST AND TORQUE"
2850   FOR I=1 TO Points
2860     Theta1(I)=Yy(I,1)-.462*Yy(I,2)+.1182*Yy(I,3)
2870     Theta2(I)=.8148*Yy(I,1)+.2996*Yy(I,2)-.2665*Yy(I,3)
2880     Theta3(I)=.44*Yy(I,1)+.44*Yy(I,2)+.44*Yy(I,3)
2890     Torque(I)=-K1*Theta3(I)*.001      !SHAFT THRUST IN KN
2900   NEXT I
2910   DISP ""
2920   RETURN
2930   !
2940 Plot_setup: !
```

```
2950 LOCATE 20,120,10+(K-1)*50,50+(k-1)*50
2960 FRAME
2970 MOVE 40,0
2980 LABEL "TIME (Seconds)"
2990 INPUT "INPUT SCALE (XMIN,XMAX,YMIN,YMAX)",Xmin,Xmax,Ymin,Ymax
3000 SCALE Xmin,Xmax,Ymin,Ymax
3010 AXES Xmax/50,Ymax/10,Xmin,Ymin,5,2
3020 AXES Xmax/50,Ymax/10,Xmin,Ymax,5,2
3030 AXES Xmax/50,Ymax/10,Xmax,Ymin,5,2
3040 FIXED 2
3050 LORG 5
3060 X=Xmin
3070 Y=Ymin
3080 IF K=1 THEN
3090   FOR I=1 TO 10
3100     X=X+ABS(Xmax-Xmin)/10
3110     X$=VAL$(X)
3120     MOVE X,Ymin-.07*ABS(Ymax-Ymin)
3130     LABEL X$
3140   NEXT I
3150 END IF
3160   !
3170 LORG 8
3180 FIXED 0
3190 FOR I=1 TO 5
3200   Y$=VAL$(Y)
3210   MOVE Xmin,Y
3220   LABEL Y$&"  "
3230   Y=Y+ABS(Ymax-Ymin)/5
3240 NEXT I
3250 STANDARD
3260 RETURN
```

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